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USAF EVALUATION OF AN AUTOMATED ADAPTIVE FLIGHT TRAINING SYSTEM

James E. Brown, et al

Air Force Human Resources Laboratory
Brooks Air Force Base, Texas

October 1975

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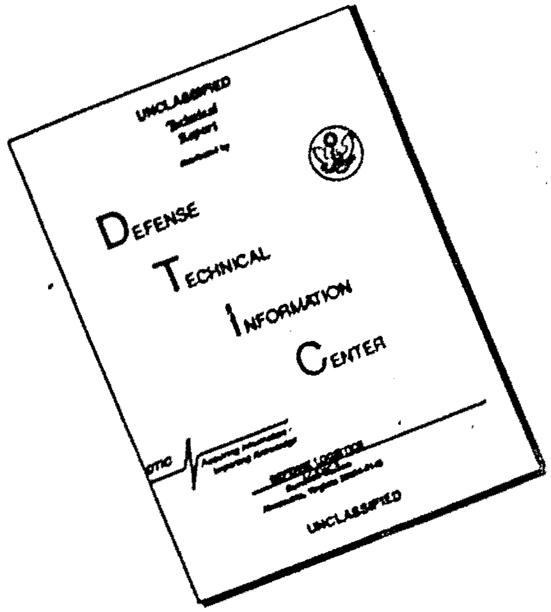

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AIR FORCE HUMAN RESOURCES LABORATORY

USAF EVALUATION OF AN AUTOMATED ADAPTIVE FLIGHT TRAINING SYSTEM

By

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FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224

October 1975
Interim Report for Period January 1974 – December 1974

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This interim report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with Hq Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.

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This technical report has been reviewed and is approved.

WILLIAM V. HAGIN, Technical Director
Flying Training Division

Approved for publication.

HAROLD E. FISCHER, Colonel, USAF
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The objectives of the study were: (1) to evaluate the training effectiveness of the Automated Flight Training System (AFTS) in the F-4 training program; (2) to identify desired hardware and software modifications for operational AFTS devices; and (3) to identify effective methods of operational training use. The study was performed at Luke AFB, Arizona at the request of the Tactical Air Command (TAC). A class of 24 students assigned to F-4 combat crew training was randomly divided in two equal sized groups. One group received GCA training using the AFTS. The other group received normal GCA training from F-4 instructors. Performance data, questionnaire data, and maintenance data were collected and analyzed. Implications of the data for future use and procurement of additional systems are discussed.

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SUMMARY

Objectives

The objectives of this evaluation study were: (1) to evaluate the training effectiveness of the Automated Flight Training System (AFTS) in F-4 Combat Crew Training, (2) to identify desired hardware and software modifications for operational devices and (3) to identify effective methods of operational training utilization of the AFTS. While the capabilities of the AFTS include adaptive training features, the present research was not an evaluation of adaptive training per se, but rather an evaluation of an entire system in which adaptive training represented only one of its many features.

Approach

Subjects were 24 students from Class 75-CRL at Luke AFB, Arizona, divided into two groups of 12 each. All were recent graduates of undergraduate pilot training who had been assigned to F-4 combat crew training in Operational Training Course F4000B.

The AFTS is a parasitic device attached to an existing F-4E simulator. The host simulator was used in normal F-4 training and did not have a visual capability. The AFTS is designed to automatically direct pilots through a series of ground controlled approach (GCA) and tactical air navigation (TACAN) exercises. It consists of a computer system, a voice generation system, a display and control system, and a system for interfacing with the host F-4E simulator.

One group of subjects received GCA training using the AFTS, while the other group received conventional GCA training administered by instructor pilots and simulator operators. Students were randomly paired so that one member of a pair was assigned to the AFTS Group and the other member to the standard GCA training group. The AFTS group pair-member received his GCA training before his Standard GCA-trained counterpart. The pair-member assigned to the Standard Group received the same presentation of difficulty levels within the adaptive training schedule as his AFTS-trained counterpart to avoid the potential criticism of unequal training provided both groups.

The GCA training was given during the first 15 sorties in the F-4 simulator training syllabus. Independent variables were a set of objective performance measures generated automatically by the AFTS for all subjects and were collected on all training sorties and on two sets of criterion sorties. The criterion sorties consisted of three GCAs each, the first set administered immediately after initial training and the second set administered approximately four months after the first criterion sorties. In addition to the objective performance measures, student and instructor questionnaire data and maintenance data were collected and analyzed.

Results

The results of the evaluation are presented and discussed according to three topical areas: (1) the training effectiveness of the system, (2) qualitative evaluation of the system, and (3) operational reliability and maintainability of the system.

Analyses of the training effectiveness results of the evaluation study showed: (1) there were no differences in performance on the training trials between the AFTS and Standard Groups, (2) the group trained by a machine controller performed as well as the group trained by human operators on the basis of the criterion sorties, and (3) the AFTS does not appear to train any adverse GCA responses as measured during the study.

The results for the qualitative evaluation of the system indicate that students and instructors liked the AFTS as a training device. Suggested changes included speeding up the transmission rate of information given during the GCA and improving message priorities to be more like real GCA controllers. The AFTS features most liked were the replay capability and the performance measurement hardcopy printout.

Reliability and maintainability data collected during the evaluation indicated that (1) the monitor buffer interface device should be improved through use of better manufacturing materials or redesign; (2) the replay system of the AFTS was found to have software problems which required modification; and (3) the 4010 Tektronix displays which were used for operator control and replay were wearing out rapidly under heavy use, and it was suggested that other display systems be examined to minimize this problem.

Implications

The results suggested that there were more difficulty levels provided by the AFTS than could be used for effective training in the F-4 program. The mechanization of the adaptive scheduling algorithm possesses several characteristics which appear to require further empirical validation prior to operational implementation. Questions were raised regarding optimizing the use of the AFTS in maintaining flying skill once a student has completed the adaptive program. It was noted that the question of whether additional Automated Flight Training Systems should be procured was not addressed in the present study and that system costs should be analyzed in terms of potential system application to answer the procurement question.

PREFACE

This effort was conducted by the Flying Training Division of the Air Force Human Resources Laboratory, Williams AFB, Arizona, and supported by the 58th Tactical Flighter Training Wing, Luke AFB, Arizona, in coordination with Headquarters, Tactical Air Command. The report represents a portion of the research program of Project 1123, USAF Flying Training Development, Dr. William V. Hagin, Project Scientist; Task 112303, Exploitation of Flight Simulation in Undergraduate Pilot Training (UPT), Mr. James F. Smith, Task Scientist. The work contained in this report was performed in support of Tactical Air Command Request for Personnel Research (RPR 73-18, 16 July 1973).

The authors are grateful to those who contributed substantially to this project. The students and instructors of the 311th Squadron, 58th Tactical Fighter Training Wing performed well throughout the six month period of the study. Major Robert MacArgel, TAC/DOXS, Langley AFB, Virginia was instrumental in getting TAC approval to conduct the program. Major Ken Ek, F-4 Instructional Systems Development Team (ISDT) served as the local TAC Project Officer. He and other members of the ISD team provided constructive comments during the formative stages of the evaluation and assisted in briefing the program at Luke AFB, Arizona. CMSgt Jim Sofianos and other members of the F-4 Development Technical Team (DTT) provided much of the equipment information on the AFTS so that the system could be effectively used. Scheduling of students into a single device presents a problem in an operational training program. The authors were very appreciative of the extra effort put forth by Major Brad Lee, 58th TFTW Scheduling Officer and Capt Ed Allen, 311th Squadron Scheduling Officer, who were able to solve the scheduling problems encountered during the study. Captain Roger Vick served as the 311th Squadron Project Officer and assisted in the study interface with squadron personnel. During the study, maintenance and operation of the AFTS was accomplished by the 58th Avionics Maintenance Squadron, Training Devices Branch, Luke AFB, Arizona. Sgt Bud Crawford and Sgt Bill Nunn worked many long days in order to insure that the system was operating properly and to solve the equipment problems that were encountered in the program. SSgt J. Lilly and SSgt D. Brown served as the GCA controllers during the two criterion tests and are commended for their efforts.

Mr. George Futas and Mr. Ed Butler of Logicon, Inc., San Diego, California provided timely and crucial engineering and software assistance during the study to insure that the AFTS remained operational.

Mr. Paul Heffner, F-4 SPO, Wright-Patterson AFB, Ohio secured the necessary funding for acquisition and maintenance of AFTS system components which made the research program a reality.

Finally, Mr. Richard Greatorex, AFHRL/FT, working in coordination with Logicon personnel, designed and installed the software modifications needed to conduct the study.

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USAF EVALUATION OF AN AUTOMATED ADAPTIVE FLIGHT TRAINING SYSTEM

I. INTRODUCTION

In August 1973, the Tactical Air Command (TAC) began acceptance of an Automated Flight Training System (AFTS) built by Logicon, Inc. The device, installed as a parasitic system on one of the existing F-4E simulators at Luke AFB, Arizona was designed to provide automated adaptive training for ground-controlled approaches. In December 1973, TAC requested that AFHRL conduct an operational evaluation of the AFTS in the F-4 combat crew training program. Through mutual agreement of both TAC and AFHRL, the evaluation was initiated in May 1974. The major objectives of the evaluation were: (1) to evaluate the training effectiveness of the Automated Flight Training System (AFTS) in the F-4 Training Program, (2) to identify desired hardware and software modifications for operational devices, and (3) to identify effective methods of operational training use. Since one of the major characteristics of the AFTS was its use of adaptive training, a brief description of the concept and related research literature will be presented.

Adaptive Training Defined

The term "Adaptive Training," typically is used to represent a training situation ... "in which the problem, the stimulus, or the task is (automatically) varied as a function of how well the trainee performs," (Kelley, 1971). It can be seen from this definition that adaptive training required: (1) "A continuous or repetitive measurement of trainee performance," (2) "One or more task variables that can be adjusted to change task difficulty," and (3) "A means for automatically adapting task difficulty as a function of the performance measurement such that the task becomes more difficult as the trainee becomes more skilled," (Kelley and Wargo, 1968).

In most instances the use of the term "Adaptive Training" refers to a training situation in which a trainee works with a device to help him acquire a skill. The properties of the device are such that the trainee receives a series of practice exercises, the difficulty of which is automatically adjusted according to how well the trainee performs. This trainee-device interaction is similar to a non-mechanized learning situation in which ... "The skilled instructor varies the difficulty of the tasks he gives to a student as a function of how well that student has been performing ... ," (Kelley, 1969).

While the development of an adaptive training device which can duplicate the performance of a skilled instructor is a dramatic achievement by itself, the potential value of adaptive training as an educational strategy seems far greater. Properly designed, adaptive training provides individualized instruction that is characteristically more accurate and reliable than that which most skilled instructors can provide. It can be adjusted and continuously refined to generate the skill required, and because of its mechanization requirements, can be computer managed once an optimized program is determined, thus obviating the need for further instructional involvement by a skilled instructor.

Additional Considerations

It has been noted that adaptive training is based on the assumed training effectiveness of automatically increasing training task difficulty as the trainee's performance improves, so as to match his increasing performance capabilities. This concept is related to an older notion of reading readiness in which the young child is prepared to be ready to learn to read by the time he starts the first grade. In practice, of course, some children are more ready than others. It is suggested that the adaptive trainee, just like the first grader learning to read, will not learn a new skill until he is ready. Most trainees begin practice with different individual skill levels, or readiness, and as a result may not benefit maximally from the same sequence of training tasks, regardless of the properties of the schedule which determines how task difficulty increases. It should be pointed out, however, that this potential problem is inherent in all learning and training situations.

Another potential problem exists in some characterizations of task difficulty where the training task is dimensionalized on the basis of face validity or convenience of mechanization. In aviation training, this takes the form of an initially simplified training task to which environmental variables, such as air turbulence or wind direction, are manipulated to generate levels of apparent increasing difficulty. This

practice is not unreasonable and seems to be based on the assumption that representativeness is equivalent to difficulty. For example, the real world has cross winds and rough air; therefore, these conditions create more difficulty for a pilot landing an aircraft than wind down the runway and smooth air. Such notions seem reasonable to the skilled instructor. Whether this scaling of task difficulty is appropriate for manipulating the practice of naive trainees is an empirical question.

Another potential problem area concerns the role of the instructor. Traditionally, he performs a number of teaching functions: testing and scoring student performances, pointing out errors, selecting the next training tasks or assigning remedial practice. Adaptive training programs, however, accomplish these tasks without an instructor pilot. In a sense, the use of adaptive training may obviate many of the instructor's favorite roles. What the instructor still will be needed to do is relate the trainee's learning to the circumstances in the real world in which the newly acquired skills will be needed and how they may best be employed. The relating of instruction to the real world is a phase of teaching that is frequently overlooked because of the obvious focus on the trainee's need to acquire the skill in the first place. Thus, the instructor may find many of his old familiar and favorite teaching tasks no longer needed and in addition may find he has to learn to perform new and unfamiliar functions in the total training system. It may, therefore, be reasonable to suspect that the instructor may experience certain frustrations in his involvement with adaptive training.

Adaptive Training in Aviation

Adaptive training concepts have been extended to aviation and have resulted in the development of several automated systems. To date, studies of adaptive training in aviation have focused on demonstrations of feasibility.

Charles and Johnson (1971) developed an automated ground controlled approach (GCA) training program for the Navy. This computerized system was the forerunner on the F-4 Automated Flight Training System (AFTS) at Luke AFB, Arizona, which was evaluated in the present effort. The program was developed for the Training Device Computer (TRADEC) System at the Naval Training Equipment Center, Orlando, Florida. A GCA flight segment was selected as the initial training task. Procedures for automated data collection recording, and student record keeping were programmed into the system. All operations of the system were performed automatically, including on-line structuring of the training course as a function of student performance. Twelve operational F-4 pilots were utilized for the demonstration. Pilot opinion indicated that the system did reflect operational GCA requirements and would be beneficial in operational training systems. It should again be emphasized that the study was primarily a feasibility demonstration of the capability to automate GCA training and not a comparative evaluation.

Charles et al., (1973) later applied the adaptive training techniques to the acquisition of basic instrument flight skills. Again, the study was performed using the TRADEC system at the Naval Training Equipment Center. Basic instrument flight maneuvers for the F-4 aircraft, straight and level, climbs and descents, level turns, and climbing/descending turns were automated. Variables such as maneuver difficulty, aircraft weight, center of gravity, and atmospheric turbulence were used to control task difficulty. Four trainees representing a wide variety of aviation skills were given training using the automated instrument flight training program. None of the trainees were operationally qualified F-4 pilots. Training was conducted in one hour sessions with each student completing as many runs as possible. Each successive flight began where the preceding one had terminated. Progress and updating were automatically maintained by the computer program. The authors concluded that an automated syllabus for training instrument flight maneuvers could be implemented and that a student performance score reflecting operational standards could be developed.

Charles et al., (1972) also conducted a feasibility demonstration on the application of automated-adaptive training techniques for air-to-air intercept training in the TRADEC flight simulator configured as an F-4. The training task included three phases: (1) a climb task under GCI/CIC control, (2) an attack phase under RIO control, and (3) a descent phase also under GCI/CIC control. Missile intercepts including head-on, forward-quarter, and beam runs were incorporated into a training syllabus. Atmospheric turbulence, aircraft configuration, and bank angle were employed as adaptive variables. Performance was measured objectively for each phase, and the syllabus was restructured based on student performance. Since the study was designed primarily to demonstrate the feasibility of automated air-to-air training, only three subjects were used. The results established the technical feasibility of the training.

As this brief review indicates, published reports to date have only documented the technical feasibility of adaptive training programs. No studies have been completed which compare these adaptive training programs with conventional training. The Navy had planned an evaluation of its version of the Automated Flight Training System, but at the time of this writing, the results were not available (Puig *et al.* 1974). Consequently, the present evaluation is one of the first studies to compare an operational adaptive training program with conventional training techniques. It should be emphasized that the present research was not an evaluation of adaptive training *per se*, but rather an evaluation of an entire system in which adaptive training represented only one of its many features.

II. METHOD

Subjects

Twenty-four students from Class 75-CRL at Luke AFB, Arizona, participated in the study. All students were recent undergraduate pilot training (UPT) graduates who had been assigned to F-4 combat crew training (CCT) in Operational Training Course F4000B. All students recently had completed the TAC Tactical Fighter Lead-In course prior to arrival. Four students had previous experience in the F-4 as weapons systems officers (WSO).

AFTS System Design

The Automated Flight Training System (AFTS) was designed to automatically direct pilots through a series of GCA and TACAN approach training exercises. The system will be briefly discussed according to its hardware and software components. A complete description may be found in the System Operation Manual for the AFTS (Logicon, 1974).

Hardware. The AFTS was modularly designed to operate as a parasitic device attached to an existing F-4E flight simulator. The host simulator was used in the normal F-4 training program and did not have a visual capability. The AFTS configuration consisted of: (1) a computer system including a Data General Nova 800 digital computer, card reader, line printer, magnetic tape drive, and two memory discs; (2) a Metrolab voice generation system; (3) two Tektronix 4010 graphic CRT consoles, one used for AFTS control and the other for student GCA replay; and (4) the monitor buffer and Y-switch, the hardware interfaces of the AFTS with the host F-4E simulator.

Software. The AFTS provided three modes of training. However, only Mode 1 was used for the evaluation. This mode provided automatic adaptively scheduled GCA training. The GCA syllabus was stored in a table format and organized in increasing levels of difficulty. Seventy-six different difficulty levels were provided. Difficulty levels were varied as a function of wind direction and speed, aircraft weight, atmospheric turbulence, and aircraft emergencies. Difficulty level incremented or decremented based upon pilot performance on a set GCA task. A scoring algorithm provided the basis for changes in difficulty levels.

Mode 2 provided a representative set of ten difficulty levels of AFTS GCA exercises. The steps were arranged in increasing levels of difficulty, and provided instructor personnel the capability to familiarize themselves with the performance requirements of AFTS GCA runs. During familiarization approaches, ground controller voice commands were given to a simulated pilot. At the completion of the run, a hardcopy listing of the simulated pilot performance was furnished from the line printer. The adaptive scheduling algorithm was bypassed in this mode.

Mode 3 provided one difficulty level of an initial TACAN approach. A final approach consisting of either a TACAN, ASR, or PAR could be selected. A complete description of the performance measurement and adaptive scheduling algorithms is presented in Appendix A.

Performance Measurement

Both subjective and objective performance measures were collected. The subjective measurement consisted of a questionnaire which was administered at the conclusion of the evaluation. The objective performance measures consisted of the number of GCAs completed, path score, gate score, total score, glide slope error, course angle error, and angle of attack error. These measures were printed out at the termination of each GCA. Appendix A presents a description of these measures.

The path score was the weighted average of the percentage of time the pilot flew the aircraft at the prescribed glide slope angle, course heading, and angle of attack. These measures were taken from the time the aircraft intersected the glideslope until it reached decision height, the point at which the landing could or could not be completed. Decision height was defined as 200 feet of altitude and normally occurred at approximately .75 miles from touchdown. A missed approach was commanded when the aircraft deviated from the simulated normal GCA approach cone for Runway 21 at Luke AFB.

The gate score essentially was a "snapshot" look at how well the aircraft was set up for landing at the decision height. In addition to information about deviations from desired glide slope angle, course heading and angle of attack, this score also reflected heading rate and altitude rate information.

The total score was computed by adding the gate score and the path score together and adding one hundred points. Within the adaptive software program, the total score was used to determine the rate of increase or decrease in difficulty level for a pilot.

For purposes of the evaluation, the AFTS software was modified to furnished root-mean-square (RMS) glide slope angle error, RMS course angle error, and RMS angle of attack error. Measurement for these scores was initiated when the aircraft reached eight miles and was terminated at decision height or at the missed approach point

GCA Training in the Normal TAC F-4 Training Program

The normal F-4 simulator syllabus consists of 22 sorties, each lasting approximately 1.5 hours. The average student receives 11 simulator GCAs of various types during F-4 training. The majority of these GCAs are given during the first eight simulator sorties.

Experimental Design

The present evaluation was performed within the framework of the normal F-4 syllabus with minor modifications. The experimental design for this study is presented in Table 1. All GCA training was accomplished during the first fifteen sorties. Students received one GCA on each of the first two simulator sorties and three GCAs on each of the remaining sorties up to and including Sortie #15. Equipment problems forced cancellation of one sortie consisting of three GCAs. Thus, a total of 38 GCAs were given during the training sorties.

The 24 student pilots from F-4 Class 75-CRL were assigned randomly to two equal groups. Twelve students received GCA training using the AFTS. The remaining 12 students received standard GCA training administered by instructor pilots and simulator operators.

To assure equivalent training between the two groups, students were randomly paired so that one member of the pair was assigned to the AFTS GCA Training Group and the other member of the pair was assigned to the Standard GCA Training Group. The pair-member assigned to the AFTS Group always received GCA training before his counterpart. The pair-member assigned to the Standard Group received the same order of presentation and difficulty levels of GCA training tasks as his AFTS trained counterpart. This yoked experimental design was used in order to avoid the potential criticism of unequal training. An overall feature of the design was that the training for the two groups was equal in terms of the sequence of presentation and the specific properties of the GCA problems presented.

Criterion sorties consisting of six GCAs each were administered to all students at the completion of Simulator Sorties #15 and #22. For each criterion sortie, three GCAs representing different difficulty levels were given by the AFTS. The same three GCAs also given by highly qualified professional GCA controllers, thereby giving each student a total of six GCAs.

Procedure

Logicon GCA Training Group. The AFTS provided training for ASR and PAR approaches. The system was designed for training using the instructor console of the AFTS. The pilot was directed by the

Table 1. **Experimental Design for the AFTS Evaluation**

Sortie	Adaptive Group (AFTS Training) N = 12	Control Group (Normal Training) N = 12	Training Days
1	1A through 12A 1 GCA per student	1B through 12B 1 GCA per student	6, 7
2	1 GCA per student	1 GCA per student	8, 9
3	3 GCA's per student	3 GCA's per student	10, 11, 12
4	3 GCA's per student	3 GCA's per student	13, 14, 15
5	3 GCA's per student	3 GCA's per student	16, 17, 18
6	3 GCA's per student	3 GCA's per student	19, 20, 21
7	3 GCA's per student	3 GCA's per student	22, 23, 24
8	3 GCA's per student	3 GCA's per student	26, 27, 28
9	3 GCA's per student	3 GCA's per student	29, 30, 31
10	3 GCA's per student	3 GCA's per student	32, 33, 34
11	3 GCA's per student	3 GCA's per student	35, 36, 37
12	3 GCA's per student	3 GCA's per student	38, 39, 40
13	3 GCA's per student	3 GCA's per student	41, 42, 43
14	3 GCA's per student	3 GCA's per student	44, 45, 46
15	3 GCA's per student	3 GCA's per student	53, 54, 55
Criterion Ride	**Criterion Test** 3 AFTS GCA's 3 GCA Controller GCA's	**Criterion Test** 3 AFTS GCA's 3 GCA Controller GCA's	61, 62, 63, 64
16–22	No GCA's	No GCA's	
Criterion Ride	**Criteiron Test** 3 AFTS GCA's 3 GCA Controller GCA's	**Criteion Test** 3 AFTS GCA's 3 GCA Controller GCA's	112, 113, 114, 115

automated voice to contact the Phoenix approach controller, establish an altitude of 3,000 feet and a heading of 210 degrees. When these conditions were satisfied and the software program had adjusted the aircraft weight, wind direction and velocity, and atmospheric turbulence, then the aircraft was positioned to 12 miles from touchdown. At a distance of 10 miles from touchdown, the pilot was instructed to make a radio frequency change and to contact the final approach countroller. The final controller "talked" the pilot down the glidepath with information about the gildepath, glideslope, and range from touchdown. The ASR approach was similar except that gildepath information was not given. Aircraft emergencies were introduced at ranges of 10 miles to 2 miles from touchdown. Students in this training group were permitted to examine the training records printed out by the AFTS and to use the playback system at any time during the study.

Standard GCA Training Group. The procedure for students in this group was similar to the AFTS trained group. The AFTS was used to set up the problem and to perform the performance measurement. However, after the pilot contacted the final GCA controller, the automated voice was locked out and the instructor pilot or console operator performed the task of "talking" the student down the gildepath.

The Situation Display Indicator (SDI) on the simulator main console was programmed to present course and glideslope information to the individual who served as the GCA controller. The GCA presentation on the SDI was displayed in a manner similar to a normal radar scope GCA presentation.

Students in this training group were not allowed to see their performance sheets or to use the playback feature of the AFTS. Instructors were not permitted to use any part of the AFTS for debriefing or feedback to the student. In short, the only feedback that students in this group received was from standard sources available in F-4 training.

Criterion Test. Approximately four months elapsed between the two criterion rides. During this interval, students did not receive further GCA training in the simulator; however, students did report receiving one or two GCAs in the aircraft.

On each criterion sortie, the student was briefed on the procedure to be followed and the conditions that were to be given for each difficulty level. Three GCAs were given, then the student was given a five minute rest period; then the last three GCAs were administered.

The same difficulty levels were administered during the first and second criterion sorties. The order of presentation of the difficulty levels was also the same for both sorties. Difficulty levels selected were: (1) Level 1, Wind 210 degrees (head wind) at 35 knots, aircraft weight 35,000 pounds, no turbulence, no emergency; (2) Level 30, Wind 030 degrees (tail wind) at 20 knots, aircraft weight 43,700 pounds, heavy turbulence, no emergency; and (3) Level 49, Wind 030 degrees (tail wind) at 20 knots, aircraft weight 43,700 pounds, heavy turbulence, left engine failure at eight miles from touchdown.

During the first criterion sorties, half the students in each training group were given the AFTS GCAs first while the other half of the students in that group received GCAs given by the professional controllers first. During the second criterion sortie, the order of presentation for GCAs was reversed.

III. RESULTS AND DISCUSSION

The results of the evaluation are presented and discussed according to four topical areas: (1) the training effectiveness of the system, (2) qualitative evaluation of the system, (3) operational reliability and maintainability of the system, and (4) recommended changes and operational utilization of the system.

Evaluation of Training Effectiveness

An examination of differences between performance data for the adaptive (AFTS-trained) and control (instructor-trained) groups provides information regarding the training effectiveness of the AFTS system. If the AFTS was to be considered an effective training system, then students in the adaptive group should have performed better or at least as well as those students in the control group. Otherwise, the operational utility of such a system would be seriously questioned. Data pertaining to this question could be divided according to source – that obtained during the training period and that obtained during the two criterion sorties.

Training Data. The original experimental design called for one GCA to be administered on the first two sorties and three GCAs on the remaining thirteen. Due to system failure, GCAs for one sortie were cancelled, thereby reducing the total number to 38. Of these, six were emergencies required by the training syllabus on specified sorties. Therefore, only 32 GCAs were administered as originally intended for each student. Furthermore, one student in the control group suffered a fractured collarbone and was placed on a medical-hold status, thereby eliminating him from the study.

Since both the adaptive and control groups received the same levels of difficulty, inferences were based on performance data rather than measures derived from difficulty levels. Nonetheless, data reflecting changes in difficulty level as a function of training trials are presented for descriptive purposes. Figure 1 presents the mean difficulty levels for the adaptive group. The data are characterized by increasing means and variability as a function of training trials and are presented in Appendix B. Plots for each individual are also presented in Appendix B.

An examination of these individual learning curves reveals certain trends. It appears that the major difference among individuals is not the slope of the learning curve, but rather the number of trials before consistent advancement in difficulty level occurs. In other words, *once the student has mastered the concept of the GCA, and what the requirements are, then he will consistently advance.* Otherwise, he remains at the lower levels of difficulty. For such students who do not master the GCA concept quickly, it is unlikely that the introduction of emergency conditions will be of any value. The individual learning curves for several students indicate this to be the case.

The most important question to be addressed by the training data concerned potential differences in performance for the adaptive and control groups. Data for the 32 GCA training trials were combined to

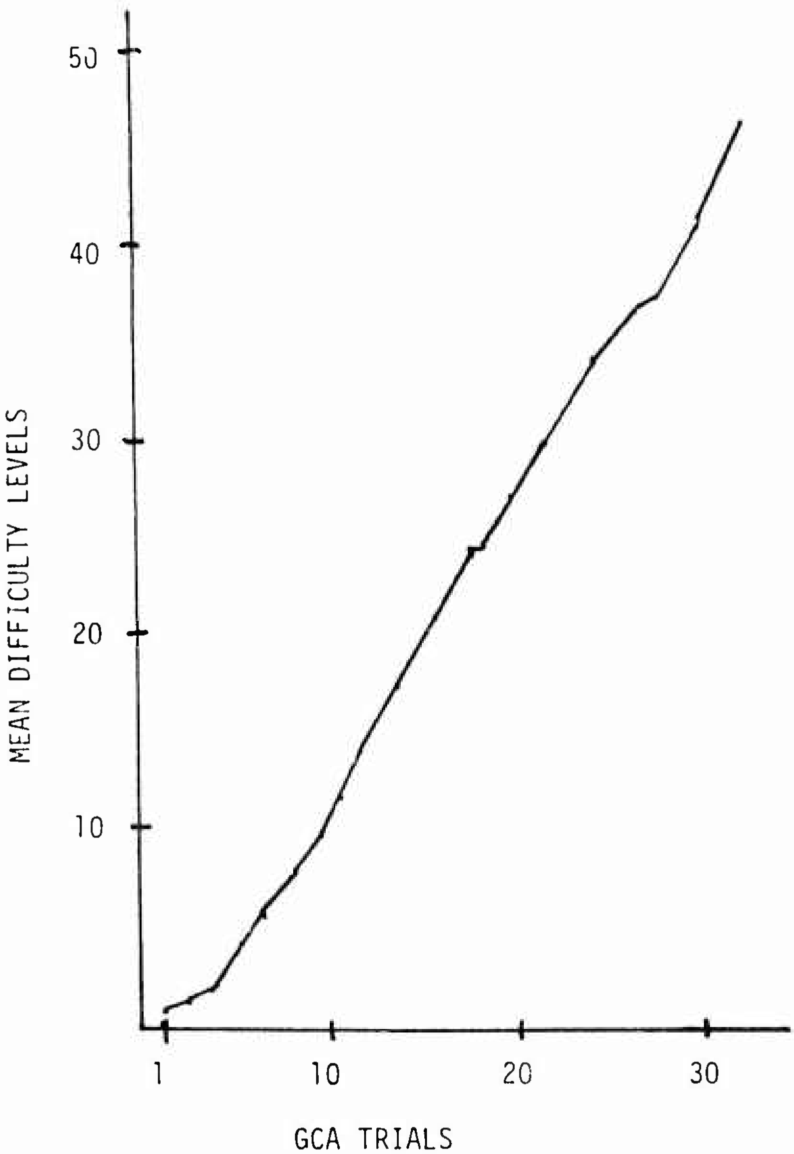

Figure 1. **Mean difficulty level as a function of training trials.**

produce 11 training blocks. The first block consisted of the first two GCAs given on the first two sorties. The remaining ten blocks consisted of consecutive sets of three training trials. For each performance measure, the block score was simply the mean of all trial scores within that block. Seven measures of performance were used -- path completion (scored 0 or 1), glide slope score, course angle score, angle of attack score, path score, gate score, and total score. Descriptive statistics were computed for these data and the results are presented in Appendix B. Mean scores for each measure pooled across all training blocks are presented in Table 2.

Each dependent measure was analyzed by a split-plot factorial analysis of variance (Kirk, 1968) having one between factor (adaptive vs control) and one within factor (training block). These results are presented in Table 3. As indicated, only the training block factors produced a significant effect for the dependent measures. Neither the group factor nor its interaction with the training block factor was significant. In other words, *the data revealed no difference in performance between the adaptive and*

Table 2. **Mean Scores for Training Sortie Data**

Measure	Adaptive	Control
Path Completin	.613	.606
Glideslope Score	58.011	59.877
Course Angle Score	64.007	66.359
Angle of Attack Score	30.279	28.277
Path Score	57.806	58.481
Gate Score	25.445	26.695
Total Score	165.158	162.663

Table 3. **Summary of Analyses of Variance for Training Data**

Measure	A	B	AB
Path Completion	.0058	8.1400**	.3290
Glideslope Score	.7018	3.8310**	.7127
Course Angle Score	.8727	2.1881*	.7268
Angle of Attack Score	1915	2.9454**	1.0656
Path Score	.1426	8.2004**	.8340
Gate Score	.1071	5.3284**	.3622
Total Score	.0322	10.7876**	.3117

*$p < .05$ A Group Factor
**$p < .01$ B Trial Block Factor

control groups. A priori t tests were computed to determine whether any group differences existed during the first training block. Again, no differences were found suggesting the initial ability levels for the two groups to be equivalent.

Since no group differences were indicated the data were pooled. Figure 2 presents mean percent of completed GCAs completed across the 11 training blocks. Figures 3, 4, and 5 present each of the remaining dependent measures as a function of training block number. The data for these dependent measures are consistent. There is an initial increase in performance through the first training blocks followed by a decrease and another increase. It seems likely that the decrease noted in blocks 5 through 9 reflect the introduction of difficulty levels requiring emergencies. In any case, *it is apparent that measures of performance do change as a function of training trials. The adaptive logic does not alter difficulty level so as to maintain the performance data constant.*

To summarize, *the data reflect no differences between the adaptive and control groups during the training period.* An examination of the descriptive statistics reported in Appendix B reveal the results to be nearly identical. It seems safe to conclude that the data indicates both groups received equivalent training. No differences could be detected.

Criterion Sortie Data. For each criterion sortie, half of the GCAs were controlled by the machine while the other half were administered by highly qualified GCA controllers. Performance under the experienced GCA controllers was assumed to represent the major criterion for evaluating the training effectiveness of the AFTS system. Simply stated, were there performance differences between the adaptive and control groups using experienced controllers? The primary concern was whether the adaptive group, trained on the machine, could effectively transfer to the GCA task using actual controllers. Aside from this

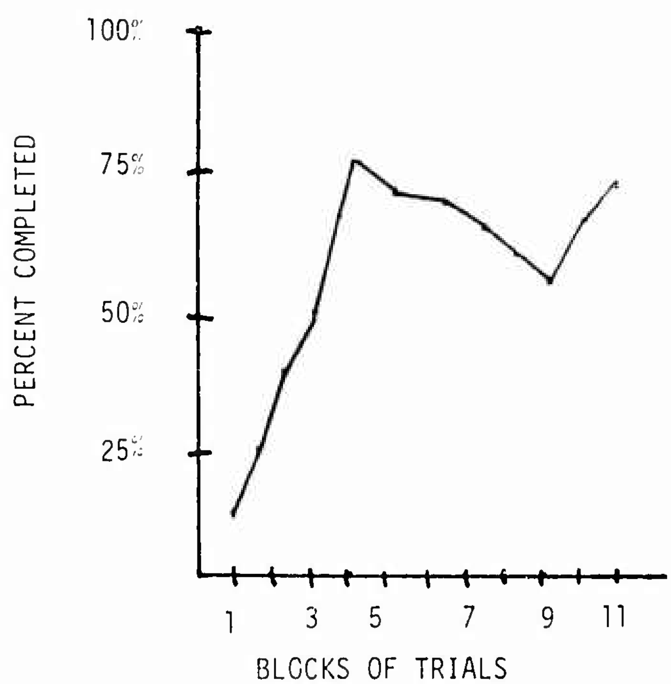

Figure 2. Mean percent GCAs completed as a function of training blocks.

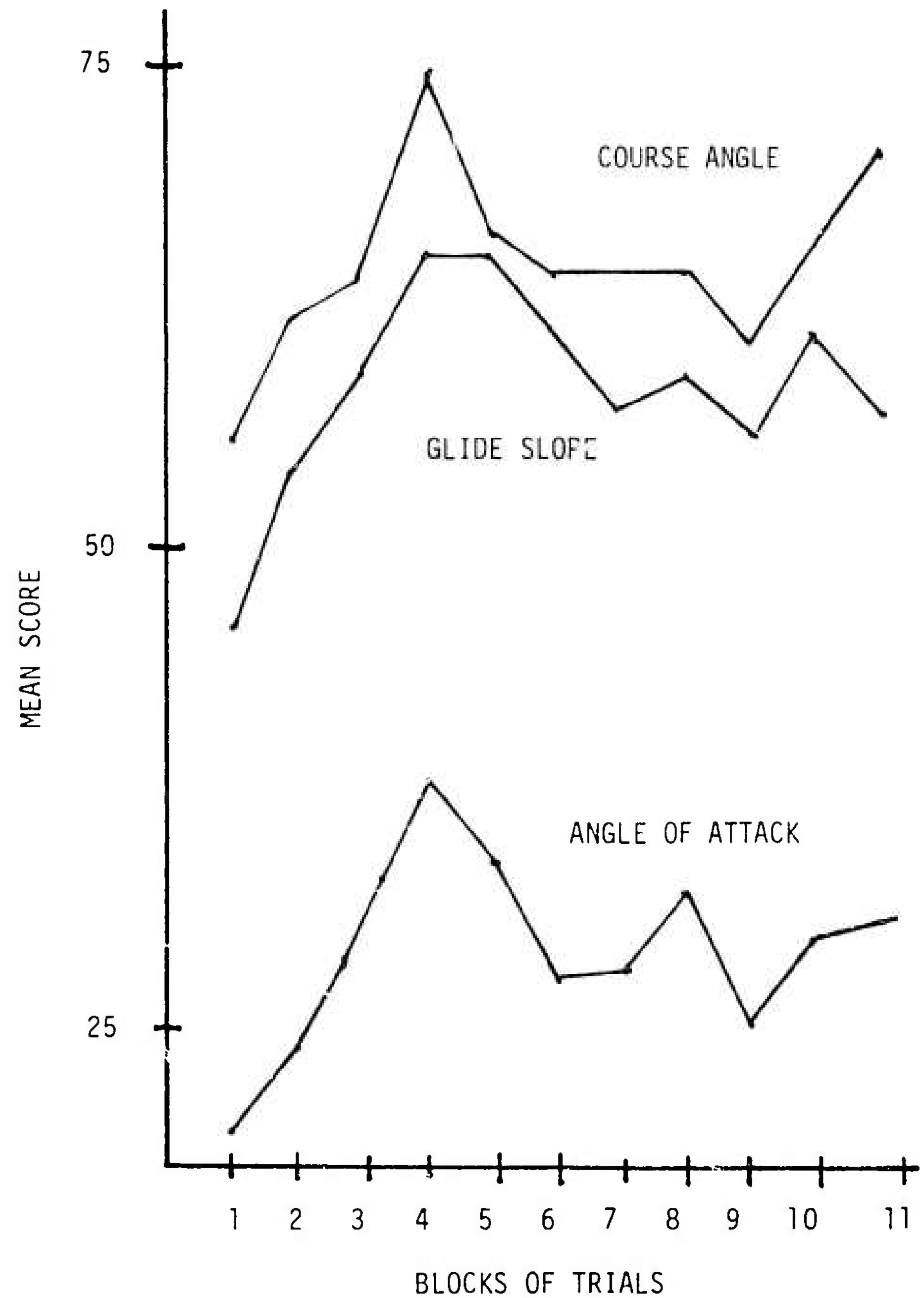

Figure 3. Mean glidepath parameters as a function of training blocks.

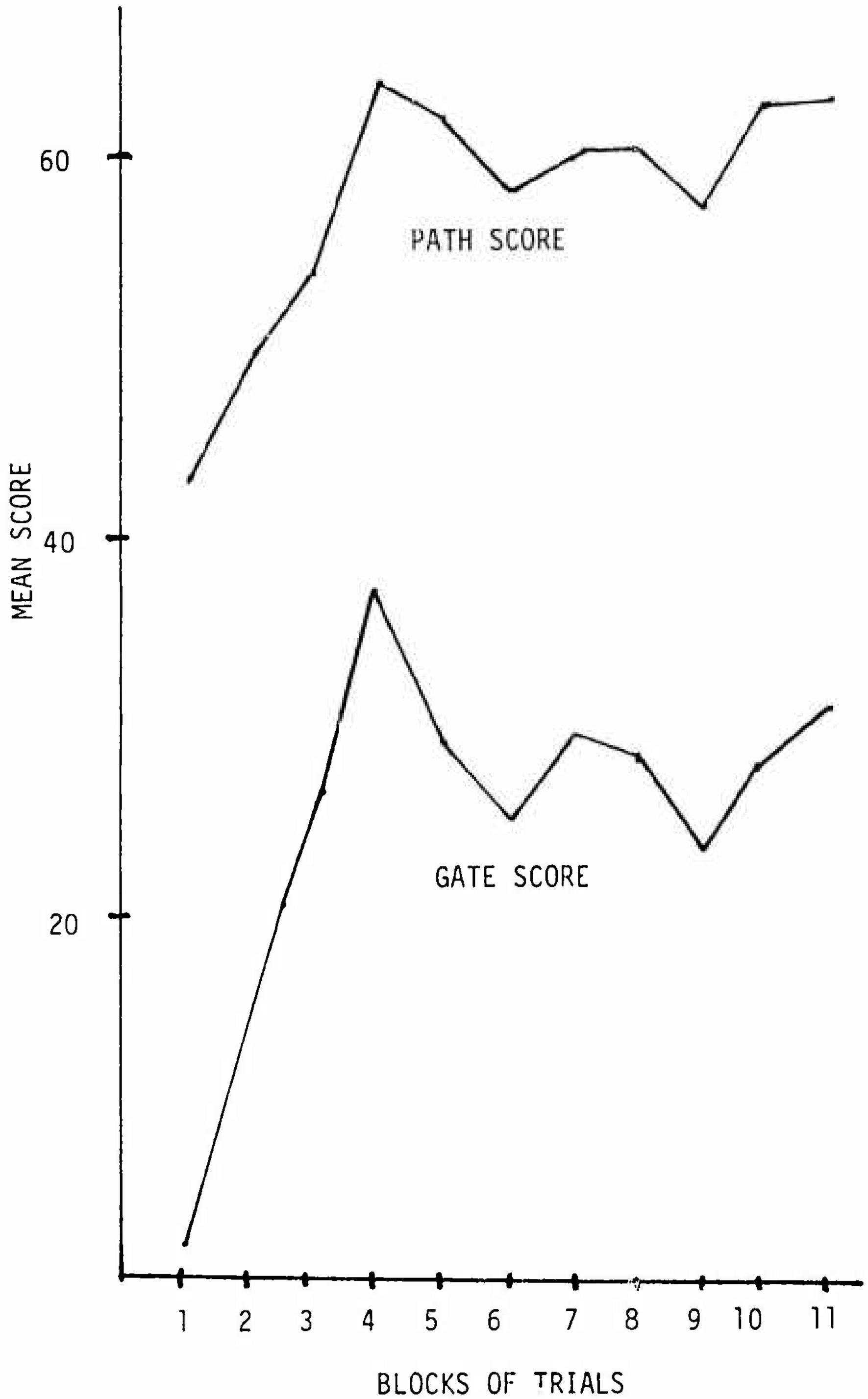

Figure 4. Mean path and gate scores as a function of training blocks.

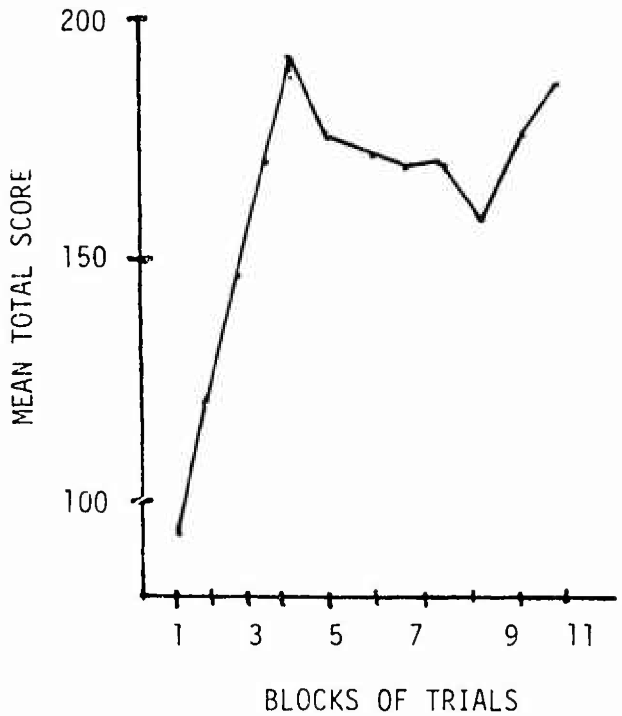

Figure 5. **Mean total scores as a function of training blocks.**

question, the data permitted an evaluation of the automated machine controller using the experienced GCA controller as the standard.

To answer these questions, an analysis of variance was performed for each dependent measure. The factorial design consisted of one between subjects factor (group) and three within subjects factors criterion sortie (1st vs. 2nd), type of controller (machine vs. human operator), and level of difficulty (Level 1 vs. Level 30 vs. Level 49). A summary of the resulting F-values for all main effects and interactions are presented for each dependent measure in Table 4.

As the data indicate, the only significant main effects were those factors reflecting type of controller and level of difficulty. Professional GCA controllers produced significantly better scores for all measures except GCA completion, RMS angle of attack, and the gate score. The group means are presented in Table 5. For the levels of difficulty factor, only the RMS angle of attack measure was not significant. Group means for this factor are presented in Table 6. The data indicate that measured performance for Levels 1 and 30 to be roughly the same, while significantly degraded for Level 49, the single-engine emergency. The exception is the path score measure wherein Levels 1 and 49 are equivalent with Level 30 yielded the better performance. However, it must be recalled that Levels 30 and 49 were flown under conditions of maximum turbulence. The measurement alogrithm adds 15 points to the path score to compensate for such turbulence. Consequently, subtracting this amount from the mean reveals Levels 1 and 30 to be roughly equivalent, with performance on Level 49 significantly degraded. Since the path score is part of the total score, the same logic applies. In summary, *the criterion data suggests performance on Levels 1 and 30 to be roughly equivalent. Performance is significantly degraded only on Level 49, the single engine emergency.*

As previously indicated, the critical comparisons were between the two groups for the GCAs conducted by the actual controllers. Table 7 presents the mean values for each of the dependent measures. A priori t-tests were computed for each measure. No statistical differences were obtained. In other words, *the adaptive group trained by the machine controller performed as well with the actual GCA controllers as did those trained by human operators.*

Table 4. **Summary of Analyses of Variance for Criterion Ride Data**

Source	RMS Glide Slope	RMS Course Angle	RMS Angle of Attack	Path Score	Gate Score	Total Score
A	.026	.300	.137	.053	1.308	.688
B	.639	.168	3.820	.981	.613	1.046
C	10.325**	24.707**	.804	40.800**	2.199	5.554*
D	26.284**	30.517**	1.078	21.322*	12.880**	11.406**
AB	.068	.000	.169	.060	1.320	.423
AC	.788	.155	1.314	1.458	.914	1.178
AD	.062	.171	.503	.175	1.028	.293
BC	.010	.111	.002	.209	.314	.025
BD	.466	1.504	.458	1.415	.336	.019
CD	1.258	1.077	.924	.286	.143	.038
ABC	.978	2.810	.008	2.736	.060	.281
ABD	1.414	.324	1.539	.129	.192	.024
ACD	.907	2.971	1.401	.877	.288	1.548
BCD	.122	2.249	2.431	.378	4.485*	4.560*
ABCD	.519	.082	.896	.356	4.192*	3.272*

*$p \leq .05$
**$p \leq .01$

A Group
B Criterion Sortie
C Type of Controller
D Level of Difficulty

Table 5. **Mean Scores as a Function of Type of Controller**

Measure	GCA Operator	Machine
Path Completion	.833	.812[t]
RMS Glideslope	.241	.294*
RMS Course Angle	.320	.454*
RMS Angle of Attack	1.885	1.820
Path Score	80.141	71.387*
Gate Score	46.627	42.629
Total Score	220.126	207.472*

[t]No Significance Test
*Significant Differences

Table 6. **Mean Scores as a Function of Levels of Difficulty**

Measure	Level 1	Level 30	Level 49
Path Completion	.935	.870	.663[t]
RMS Glideslope	.214	.208	.380*
RMS Course Angle	.284	.323	.553*
RMS Angle of Attack	1.737	1.834	1.991
Path Score	71.078	85.386	70.838*
Gate Score	52.882	48.439	32.650*
Total Score	221.448	226.794	193.157*

[t]No Significance Test
*Significant Differences

Table 7. Mean Group Scores for GCAs Administered by Professional Controllers

Measure	Adaptive	Control
Path Completion	.861	.803
RMS Gildeslope	.236	.247
RMS Course Angle	.339	.299
RMS Angle of Attack	1.895	1.874
Path Score	76.976	75.981
Gate Score	48.251	44.974
Total Score	221.412	218.723

The only significant interactions involving a group effort were for the gate score and total score measures. An analysis of the fourth order interaction for the gate score revealed that the adaptively trained group performed significantly better on Level 30 during the first criterion sortie in which the machine served as the controller. The total score produced similar findings. T-tests between the groups for each difficulty level revealed no differences whenever the human GCA controllers were providing commentary.

Considering the data collected during the two criterion ride sorties, it is apparent that no reliable differences in performance could be detected between the adaptive and control groups. *However, the trends of the criterion test data reflecting somewhat better performance of the adaptively trained students and the high total scores for both groups lead to the conclusion that the AFTS is an effective system for training GCAs. The machine appears to train as well as the instructor and apparently does not train any adverse GCA responses as measured during this study.* Although the data have clearly established AFTS to be an effective training device, the cost-effectiveness of the system remains a question beyond the scope of the present evaluation.

Qualitative Evaluation of the AFTS

At the completion of the final criterion sortie, a questionnaire was developed to furnish qualitative information about the AFTS. It was administered to students, instructors, and GCA controllers who participated in the evaluation. Section I of the questionnaire examined specific operating characteristics of the AFTS and recommendations for change. Section II dealt with how the system was used and how its use could be improved. Comments for all groups of respondents have been summarized and are presented as follows:

Section I. List things liked, disliked, and recommended changes for each of the following phases of AFTS system operation.

A. Set-up to final GCA controller

Students and instructors pointed out that when a strong crosswind was present, the automated controller did not have the pilot make a wind correction until the final approach. This was often too late to take corrective action and resulted in a poor GCA or a missed approach. The GCA controllers indicated that a good controller would pick up the inbound aircraft much earlier if course corrections were required. Another complaint of the controllers was that the AFTS does not give the pilot enough corrective information early in the approach.

Students stated that if multiple approaches are to be performed at different difficulty levels, more time should be allowed after changing the aircraft gross weight and configuration so that the aircraft can be trimmed before starting the approach. Another major objection about the set-up configuration of the AFTS was that the system initially instructed the pilot to climb to an altitude of 5,000 feet and a heading of 210 degrees. Upon reaching the assigned altitude and heading, the AFTS then instructed the pilot to descend and maintain 3,000 feet and a heading of 210 degrees. There is no apparent need to climb to a higher altitude than 3,000 feet.

B. Final controller operation (Voice/corrections)

Students and instructors indicated that AFTS voice commands were too slow. Comments from both groups stated that the machine was unlike an actual controller in that it was unable to adjust its instruction rate to different pilot correction rates. Instructors stated that the apparent lag in instructions required the student to anticipate control responses. Examination of the voice generation system for the AFTS show that this criticism will be difficult to overcome with the present system. The Metrolab voice system uses fixed length half second phrases; thus, the only method of increasing the number of words delivered in a fixed length phrase would be to put more words on the half second phrase unit.

A frequent complaint about the AFTS was that the priorities of voice corrections need to be changed or reexamined. The priority of azimuth and elevation corrections were difficult for the machine to give simultaneously Often, the AFTS would give instructions for correcting one type of error while ignoring another. Students and instructors indicated that at longer ranges from touchdown, pilots need heading information; as the aircraft nears touchdown, glideslope information becomes more important. GCA controllers stated that priorities on trend information are unrealistic. Corrective information should be given first and then information about error is given. The controllers suggested that priorities should be to give information dealing with the features of the approach in greatest error; e.g., if the aircraft is on proper glide slope but going off on heading, then the AFTS should give the heading information prior to the glide slope information.

Students, IPs, and controllers indicated that the angle of attack aural tone is cut out when an instructor or a real GCA controller is giving instructions over the communications system. Since students and pilots use the aural tone to maintain the desired angle of attack, this problem should be examined and modifications made to the simulator communications system if appropriate.

Students and instructors commented that the AFTS controller appeared to give corrections when no corrections were required. For example, if the aircraft was steady at 210 degrees, the AFTS would command "On Course, Turn left 208." This message often was followed by the instruction "Left of course, turn right to a heading of 210 degrees." Heading information was given too often with many one degree corrections. This problem can be solved by changing the AFTS error tolerances to realistic levels.

C. Performance measurement (print-out)

Students, instructors, and controllers stated that this feature of the system was excellent. Students suggested that the system should give a grade for smoothness and consistency of performance. They also indicated that angle of attack for emergencies such as single engine failures should be modified so that students are not downgraded for flying a different angle of attack if necessary. Although students found the printout to be an excellent motivational device, they commented that the printout should be better explained and critiqued so that students and instructors know how to use the information provided.

Instructor comments indicated that although they considered the printout to be a valuable tool for debriefing the student, several improvements should be considered. The gate score appears to receive too much weight in the performance score of the student. It was suggested that the scoring at missed approach should include the number of feet left/right and above/below the required decision height. This information would allow the student and instructor to evaluate the approach more effectively than the present information permits.

Although it was labeled as a minor comment, several instructors stated that the present printout tends to waste paper with only one printout per sheet. They suggested the use of a CRT read out with the capability of getting hardcopy is desired.

D. Replay Capability

All students and instructors who participated in the evaluation and who were exposed to the replay feature of the AFTS commented that this was the outstanding feature of the system. Although students in the control group were not exposed to the replay feature, several students from this group commented that they would have liked such a feature.

During the evaluation, an attempt was made to measure the amount of use of the replay system by having aircrews sign in and out when they used it However, this method did not prove to be effective and

the information was requested in the questionnaire. As might be expected, student responses ranged from "infrequently" to "often." The majority of students indicated that they used the system as much as possible because it permitted them to see what had been performed correctly and what errors had been made.

Students commented that the replay system frequently was unavailable for use because it was located in a standard briefing room which was used by other aircrews. Another problem in using the replay feature was the result of the long training days which were sometimes experienced: students and instructors simply were too tired or too busy to use the system at the moment they completed their simulator training. Several students and instructors suggested the possibility of placing the replay terminal in the squadron or other more convenient location.

A frequent comment from students and instructors was that the replay system should be made easier to use by non-programmers. The present replay system required the user to enter several abstract programming instructions to the machine in order to use the replay. This criticism could be satisfied by developing a human engineered format which would lead the user through the correct sequence of operations. Ideally, the only specific knowledge that should be required of the user is how to turn the replay system on and off

E. Task sequencing (changes in level of difficulty)

Students, IPs, and GCA controllers indicated that the task sequencing of the AFTS is good in that it permitted the students to progress at a rate commensurate with their skill level. Controllers stated that a 35 knot head wind is not realistic. They suggested that a better training difficulty problem would be to use a 90 degree crosswind or gusting winds of some type. Although control group students were not exposed to the automated task sequencing, most students in this group indicated that they would have liked this type of training.

Section II. Discuss each of the following questions:

A. How realistic is the system?

Eighty-two percent of the students considered the AFTS a realistic system for giving GCA training. Instructors stated that compared to the realism of the F-4 simulator, the AFTS is the most realistic portion of the training received in the simulator. Instructors and GCA controllers suggested that the realism of the AFTS can be enhanced by adjustments in the priorities of the messages and increases in the rate of information from the automated voice.

B. How effective is the system in terms of enabling you to fly GCAs in the Aircraft?

Eighty-nine percent of the students stated that the AFTS provided good instrument cross-check training and that the training was effective for them. Instructors supported the value of the system and indicated that the system gives better GCA training than normal IP training because of the standardized program. IPs stated that they do not get enough practice giving GCAs to become proficient in providing GCA training. Another factor identified was that Luke AFB is a fair weather base; therefore, students receive very few GCAs in the aircraft Several instructors said that it might be a good idea to bring in real GCA controllers periodically to give training to students, but still use the AFTS measurement system.

C. What is the most effective way to utilize the system in operational training?

Student opinion for this question was equally divided. Responses indicated that the system should be used in an individualized instruction mode or as the study used the system with a specified number of GCAs required for each simulator mission. The majority of the students indicated that they would like to see the objective scoring system applied to air attack, low level radar attack, and radar land mass training. Instructors concurred with the comments of the students and suggested that the simulator equipped with AFTS be the only training system used to train GCAs. The majority of the instructors strongly urged that the GCA training should require the proper radio calls by the aircrews. Instructors pointed out that the AFTS could be used to decrease the number of aircraft GCAs that TAC Manual 51-34 requires every six months. Most instructors believed that students should be permitted to schedule GCA training, but bring the AFTS grade sheet to the instructor for signoff that training has been accomplished.

D. What should be the role of the instructor in training GCAs using the AFTS?

The majority of students stated that an instructor is not required for GCA training using the AFTS. Students and instructors stated that the role of the instructor should be to judge the learning trend of students, critique student performance, monitor the AFTS, and to help the student correct errors. Several students suggested that instructors should give an occasional GCA so that the student does not get used to the same voice, phrases, and correction rates.

E. What is the one thing you liked best about Logicon and what is the one thing you disliked most?

Students identified the following features of the AFTS as the things they liked about the system: (1) printout of performance; (2) replay capability; (3) standardization of training; (4) capability to use AFTS without reliance upon instructors; (5) the challenge of trying to beat the machine; and (6) the variety of GCAs using different winds, aircraft weights, turbulence, and emergencies. Instructors stated that the features of the AFTS which they liked most were (1) standardization of training; (2) replay capability; and (3) the printout of performance. The AFTS features disliked most by students were (1) the slow rate of the voice transmissions; (2) the lack of trend information in sufficient time to use it; and (3) some of the emergency conditions were not realistic. Comments made by instructors supported the student list shown above and added one additional item. The simulator/AFTS communications system does not permit the instructor to give the student directions from the console without blanking out the angle of attack auditory signals.

In summary, students and instructors liked the AFTS as a training device. *Suggested changes included speeding up the transmission rate of information given during the GCA and improving message priorities to be more like real GCA controllers.* To use the device effectively, *students and instructors suggested permitting the student to schedule his own GCA training and use of the device for individualized instruction. The suggested role of the instructor was to critique student performance and assist the student to overcome learning difficulties.*

Reliability and Maintainability of the AFTS

During the initial formulation of the study, it was anticipated that the system would be subjected to much use during the operational evaluation. Since the USAF was considering procurement of additional systems, it seemed necessary to collect maintenance information during the conduct of the study. As it turned out, the conduct of the AFTS operational evaluation was very beneficial from the viewpoint of identification of system hardware and software problems. The device had been accepted by TAC engineering personnel prior to the study and few problems were expected. However, by conducting the evaluation in an operational setting, hardware and software items that had been successfully demonstrated during acceptance testing were found to have deficiencies. The majority of these items were fixed rapidly by the contractor working in close coordination with USAF personnel.

Appendix C presents the maintenance problems identified during the evaluation. The major areas included:

A. Monitor Buffer Interface

The monitor buffer serves as the interface device between the AFTS and the GP-4B computer of the flight simulator. During the initial part of the study, an intermittent problem emerged which resulted in a complete system failure requiring the AFTS to be re-booted. The frequency of system failures increased to the point where the continuation of the evaluation was in question. The contractor was contacted and the hardware problem was isolated and remedied. It appeared that certain insulation had deteriorated, thereby resulting in intermittent system failures.

B. Use of the Replay System

During the first month of the evaluation, students and instructors complained that the AFTS replay would not work when they wanted to use it. It was found that the problem was due to a software error which had gone unnoticed during earlier use of the system. The software problem caused the replay system to be unusable when another student was using the AFTS for simulator GCA training. This difficulty was corrected by the contractor and USAF personnel. No further problems were experienced.

C. Replay Display Screen

The 4010 Tektronix displays which are used for operator control and replay were wearing out rapidly due to use. This problem was caused by the way that the system displays the same information on the same location of the display screen. Thus, the display phosphors became worn and blank spots began to appear on the screen. Future systems should examine other displays to minimize this problem.

Recommended Changes and Methods of Utilization

The recommendations for future changes and use of the system are based to a large degree on the individual student training records. Throughout the training sorties, individual performances of adaptively trained students were plotted on individual graphs to show progression in difficulty levels. Students in the adaptive group were allowed to inspect their performance graphs whenever they wished. Most students monitored their charts on a daily basis. Since the control group performed GCAs at difficulty levels determined by their trained counterparts, only the performance of the adaptive group was plotted.

Figure 6 shows a plot of difficulty level achieved by number of GCA trials for the evaluation. Data are shown for Student 2, Student 11, and the theoretical maximum advancement rate that could be achieved. Appendix B contains graphs for all adaptive trained students. Shown in each graph are the six TAC F-4 Syllabus required GCAs discussed previously. These GCAs were required by all students in both groups and were given during the same sorties in training. Students in both groups resumed the experimental part of their GCA training on the sortie immediately following the required training. The mandatory GCAs were as follows:

Level 31 – Utility Hydraulic Failure at eight miles from touchdown, aircraft weight 35,000 pounds, winds 210 degrees at 35 knots, no turbulence;

Level 42 – Single Engine Failure (right engine), the engine was failed prior to the start of the GCA, aircraft weight 35,000 pounds, winds 210 degrees at 35 knots, no turbulence.

Level 41 – Single Engine Failure (left engine) at eight miles from touchdown, aircraft weight 25,000 pounds, winds 210 degrees at 35 knots, no turbulence.

Level 61 – ASR Approach, aircraft weight 35,000 pounds, winds calm, no turbulence.

Level 62 – ASR Approach, aircraft weight 35,000 pounds, winds calm, no turbulence.

Level 56 – No Gyro Approach, aircraft weight 35,000 pounds, winds 210 degrees at 35 knots, no turbulence.

Initially, the insertion of these required GCAs into the evaluation was viewed with some concern since it represented a departure from the planned experimental design. However, these GCAs did provide information about the training task which otherwise might not have been collected.

The two students whose performance are shown the graph were selected as representative of both ends of the GCA performance continuum in the evaluation. As shown in Figure 6, Student 2 did very well during training (in actuality, he was the highest achieving student in the Adaptive-trained group). Student 11, who was one of the lower achieving AFTS trained students, got off to a slow start but in later GCA trials was able to establish a rate of advancement equal to that of Student 2. Both students had advancement rates equal to the theoretical maximum increment at the end of their training.

It is interesting to note how each student responded to the syllabus required GCA difficulty levels. Examination of Figure 6 indicates that the performance of the best student was unaffected by the extreme changes in difficulty levels. Student 11 still was having great difficulty in learning the initial GCA task (level 1). The introduction of the syllabus required difficulty levels did not hurt his performance, but neither did it help. This student presumably was trying to discover the relevant cues of the GCA task when the syllabus required GCAs were given. The additional cues presented during the syllabus required GCAs conceivably added to an already unmanageable number of cues. Thus, the student received very little, if any, training benefit from these GCAs because he simply was not ready for it.

Recommended AFTS Changes Based on these observations, it may be more advantageous to permit students to practice the same difficulty level until the GCA task is learned. The data for Student 11 and other low achievement students provide support for this contention.

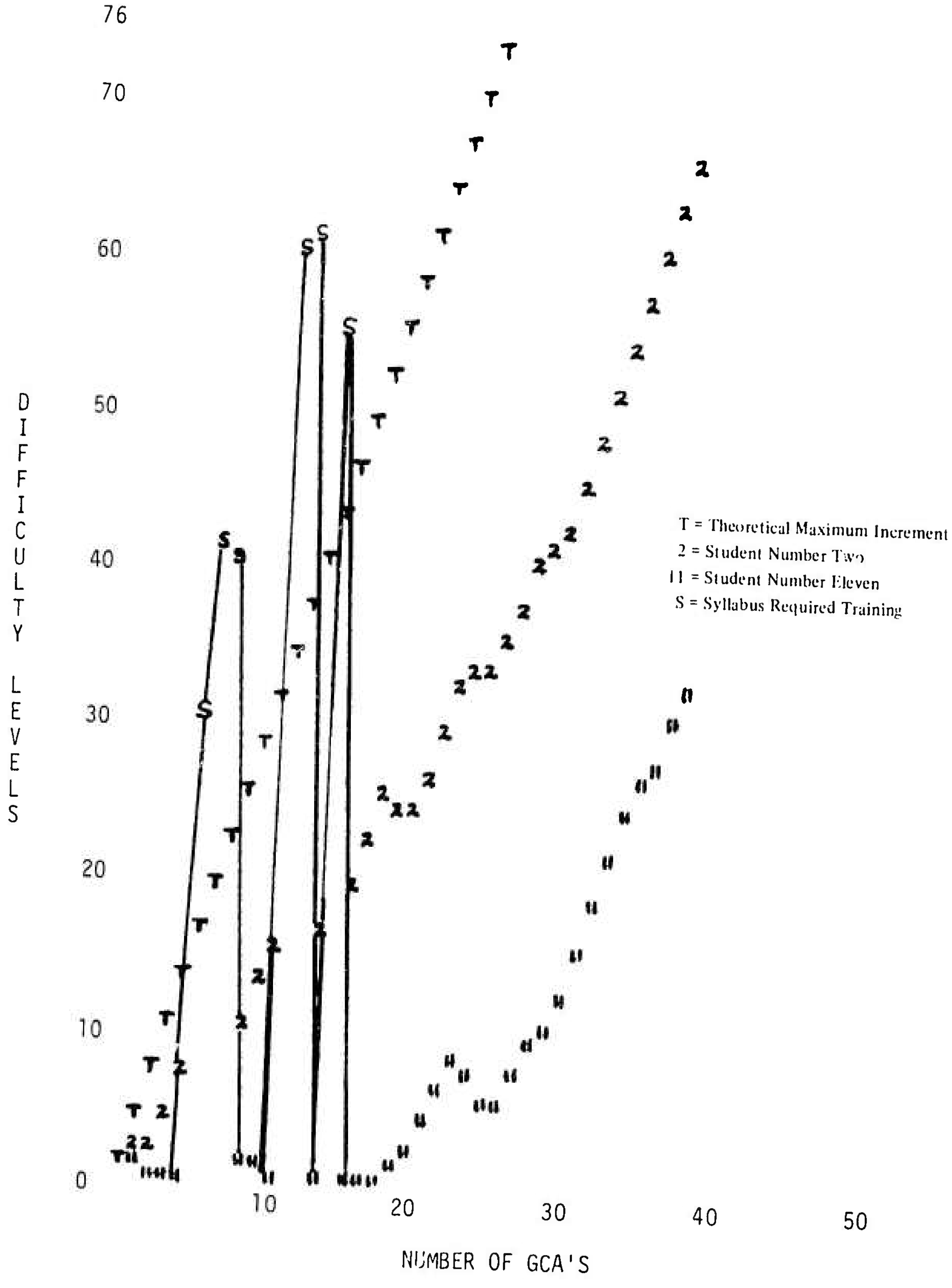

Figure 6. **Graph showing difficulty level achieved by selected adaptive–trained students during the evaluation.**

Students should be exposed to examples of different winds, aircraft weights, and atmospheric turbulence. However, the requirement for students to adaptively receive all combinations of these variables does not appear to be necessary or efficient for training. Indeed, data from this study suggest that the number of difficulty levels based upon these variables can be reduced considerably without affecting the training value of the AFTS. Thus, the difficulty introduced by these variables appears to be more imaginary than real. The introduction of emergencies (engine failures, flap failures, etc.) or different variations of GCAs (ASR Approaches and No-gyro Approaches) appear to be variables that make the GCA task difficult. In these instances, the student is forced to fly a GCA that is not normally flown. In both cases, he must transition such skills that he has previously learned to the new task.

In the present evaluation, students received 32 GCAs. Yet, the best student advanced only as far as Difficulty Level 68. The normal F-4 program does not have sufficient time allocated to GCA training to permit students to achieve this level. Nonetheless, it is above Difficulty Level 30 that the student is exposed to GCA emergencies and other variations of GCAs. Thus, as the AFTS is designed at present, the standard F-4 student pilot will miss this training unless the system is manually set to these levels; thereby taking away a potential advantage of adaptive training.

In view of these considerations, *it is recommended that the first thirty difficulty levels be examined with the aim of reducing the number of these steps. Students should be required to master these steps before moving into the emergency GCAs.* The lower number of difficulty level steps will permit students to complete the GCA instruction program in the AFTS during the normal F-4 training program. From an education standpoint, this will provide the student with a sense of accomplishment but it opens up yet another problem which must be considered. What happens to the student who reaches Difficulty Level 76? Does the student stay at Level 76 or should he be given other difficulty levels? The answer to this problem has not received adequate attention by other researchers and was not considered in the present AFTS design. Future adaptive system designers should considers additional, new approaches to this problem.

Recommended Methods of Use. Training devices like the AFTS are best suited for programs which place high emphasis upon individual instruction and proficiency advancement. For reasons of experiemental control, the present evaluation did not use the AFTS in this manner. However, the demonstrated training value of the Logicon System on the F-4 would suggest that in the future it should be utilized to maximize training value.

IV. IMPLICATIONS

The results of the evaluation indicated the AFTS to be an effective system for training GCAs. A major concern was to determine whether the AFTS provided any negative training. Throughout the evaluation, no information was gathered suggesting this to be the case. Aside from the major conclusion regarding the training effectiveness of the system, the data seemed to warrant implications in several areas.

Modification and Use of the System

The evaluation surfaced a number of areas in which modifications to the system should be considered.

Ease of Use. The present AFTS should be made easier to use by nonsophisticated users. This modification would serve to encourage students and instructors to use the replay feature and other program features of the system. An instruction program written in everyday language would accomplish the goal of removing apprehension that new users have about using the system and also would serve to involve the user in system operation.

Difficulty Levels. The requirement for 76 Difficulty Levels is questionable. The individual student learning data suggest that fewer difficulty steps will be adequate for training. Indeed, the use of difficulty levels raises several questions which should be examined.

How many difficulty levels are required in the AFTS? Although students in the study received more GCA training than the normal F-4 syllabus required, none of the students reached the top difficulty level (e.g., Student #2 reached Difficulty Level 68 in 32 trials). Thus, normal students probably will never be

exposed to all of the training conditions available in system. Without bypassing the adaptive scheduling feature of the AFTS, lower achieving students will not be exposed to GCA emergencies presently required in the F-4 syllabus. Thus, the number of difficulty levels should be reduced to the number of steps that can be accomplished realistically in a training program. This modification will result in a reduction in software program size and will set up attainable flying training goals. The exact number of difficulty levels will depend upon the GCA training objectives identified by the Tactical Air Command.

Which difficulty levels should be retained in the AFTS? The answer to this question lies most appropriately in the domain of instructional systems development. Detailed specification of the AFTS training objectives will not only reduce the number of difficulty levels, but will result in identification of the type of GCA training to be accomplished. The data from the evaluation indicated that factors such as wind direction and speed, aircraft weight, and atmospheric turbulence do not significantly effect pilot performance in GCAs after the basic GCA task has been mastered in the AFTS. Emergency conditions which require either an aircraft configuration change from normal or which increase the task workload of the pilot are factors that change the *real* difficulty of the GCA task. Application of instructional systems development principles will assist in identification of the desired difficulty levels. Additionally, it is recommended that a student data bank system to collect data on pilot performance for specific GCA difficulty levels will be of significant benefit in determining which difficulty levels should be retained in the AFTS.

Adaptive Scheduling Algorithm. The performance formula by which the AFTS increases or decreases the difficulty level of GCA training is called the adaptive algorithm. Appendix A shows the performance algorithm used in the present AFTS. However, it should be understood that the formula was based upon analytical derivation. As shown in the formula, Path Score and Gate Score receive equal weighting in the scoring algorithm. Similarly, glideslope, course, and assigned angle of attack receive equal weighting in the computation of Gate Score and Path Score. Yet, the adequacy of these formulas should be empirically verified to determine the contribution of each performance parameter to pilot performance.

An issue which is separate but related to algorithm design concerned the number of steps that pilots should be incremented or decremented based upon performance. The AFTS presently will increase difficulty levels up to a maximum of three levels. However, the efficiency of this limit is subject to question. In fact, is it necessary for the AFTS to set students back in difficulty levels based upon performance? Several instructors in the evaluation suggested that the system should increment but not decrement students. The individual student learning data shown in Appendix B suggest that early in GCA training, pilots could be retained at a given difficulty level until a high level of GCA performance skill is attained. Succeeding changes in difficulty level then might be increased (in relation to skill level) up to a maximum of four, five, or more steps. The precise number of steps for changes in difficulty level should be reevaluated so that the AFTS progression formula can be made more efficient.

Maintenance of Flying Skills. A question which is rarely considered by most proponents of adaptive training or adaptive scheduling is what happens when the student reaches the highest difficulty level. The AFTS does not consider this question. Yet designers of automated systems in flying training should consider the issue. If the student reaches the top step in the program, how should his skill be maintained in a given task? If he stays at the most difficult GCA training step, then skills on lower difficulty levels (i.e., various GCA emergencies) may not be retained. Other approaches would suggest that the AFTS program should restart the student at the beginning difficulty levels for emergencies or that a special test program incorporating selected emergency GCA difficulty levels be used. The recommended solution based upon experience from this evaluation is a combination of previously mentioned approaches. When pilots attain the top GCA difficulty level of the AFTS, the software program should automatically change the student to a special skill maintenance program. This program would consist of selected GCA emergency difficulty levels. If the student had difficulty with a particular emergency, the program would branch automatically to the main AFTS training program for remedial training. Upon completion of the remedial training, the students GCA training would be returned to the skill maintenance program for continuation training. Other equally effective skill maintenance programs can be conceived; however, all approaches should be carefully evaluated with respect to instructional objectives.

Optimizing System Use. As with most recent training innovations, automated training systems such as AFTS are designed for individualized student instruction. Efficient and cost-effective use of these systems can be realized through training programs that emphasize individualized student proficiency advancement.

Procurement of Additional Systems

Should additional automated flight training systems be procured? This question cannot be clearly answered based upon data from this evaluation. The primary issue of the study was to determine training effectiveness and consequently, the experimental design reflected this consideration. No attempt was made to save time or to effect other efficiencies in system use. Certainly, the system was effective for GCA training in the F-4 program. The AFTS provides standardized training so student skill capabilities can be described quantitatively. This intangible attribute is considered one of the major values of the system. However, the issue of cost in relation to application must be considered. The AFTS trains one small but specialized training area: GCAs and TACAN approaches. Yet, in the present F-4 syllabus, students receive approximately 10-12 GCAs and even fewer TACAN approaches in the simulator. This fact is not intended to criticize the F-4 training program, but merely to point out the small amount of time that the AFTS system would be used in the normal training program.

Present configuration of the system requires that an operator or instructor be present to monitor the student during GCA training to insure that the student performs proper GCA communications rather than merely keying the microphone switch. Thus, cost savings due to elimination of personnel cannot be realized.

Based upon these considerations, it is recommended that the Tactical Air Command consider the utilization of the device in relation to its value in standardization of training. The addition of other training areas such as ground controller intercepts (GCI), ground attack radar (GAR), navigation, and air refueling capabilities could provide increased utilization of the system. When these training features become available, the improved AFTS should be evaluated for training value and cost-effectiveness.

Adaptive Training

It should be re-emphasized that the present study was not an evaluation of adaptive training, but rather an operational system in which adaptive training was only one of its many characteristics. The experimental group, in addition to the adaptive scheduling based on their own performance, received GCA training with the following characteristics: (1) standardized instruction for all GCAs; (2) knowledge of results from the performance measurement print-outs; and (3) feedback using the replay capability. Consequently, it was impossible to assess the contributions of each of these characteristics to the training effectiveness of the system. Nevertheless, there were characteristics of the data which do reflect upon the concept of adaptive training.

One of the major requirements of adaptive training is that variations in the adaptive variable should produce changes in task difficulty. It is assumed that the resulting sequence of tasks is arranged in order of increasing difficulty. As indicated previously, the 76 levels of difficulty in the AFTS were defined with the aid of experienced instructors from the F-4 Instructional System Development Team (ISDT). That these discrete steps actually represent a series of increasingly more difficult tasks–as measured by actual performance–remains unverified. The collection of such data, using a sample of experienced pilots, would be tedious and time-consuming. The data available from students within the study are confounded by the fact that the information was collected during actual training. As indicated in the results, performance data varied as a function of training trials. It is apparent that task difficulty is not varied sufficiently in order to maintain a constant level of performance. Such information suggests that either: (a) the adaptive variables used in this training system do not actually produce difficulty changes; (b) the sequence of 76 tasks does not represent a set of increasingly difficult tasks; or (c) the adaptive scheduling algorithm is inappropriate.

An underlying assumption of adaptive training is that learning represents a continuous process. On each succesive trial, skill is incremented by a certain amount. While such continuous increases in skill level may be seen from group learning curves, it is rarely the case with individual learning curves. As stated earlier, the learning curves generated by the 12 students suggest mastery of the GCA to represent a process of insight. In other words, students will not advance until they have mastered the concept of the GCA. Once mastered, however, students advance at much the same rates. Such data suggest that once the student "learns" to fly the GCA, variations in wind velocity, direction, aircraft weight, and turbulence have little effect on his performance. Only emergencies in which the aircraft configuration is dramatically changed will affect his performance.

It is the opinion of the authors that while variations in wind, weight, and turbulence may add realism to the task, these changes based on performance within the adaptive context do little to facilitate learning. It is suggested that a random presentation of GCAs under these conditions may be as effective as the present system utilizing adaptive scheduling. However, such a statement is a matter of conjecture and is certainly in need of empirical validation. Future studies comparing adaptive scheduling with random and/or fixed presentation would test the utility of the adaptive scheduling feature.

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APPENDIX A: DESCRIPTION OF AFTS PERFORMANCE MEASUREMENT, ADAPTIVE SCHEDULING AND LEVELS OF DIFFICULTY

The measures of performance used in the evaluation will be discussed in two categories--those delivered with the AFTS and those developed for the evaluation.

AFTS Performance Measures. The AFTS provides three primary scores–path score, gate score, and a total score. The path score reflects performance down the glidepath while the gate score reflects aircraft parameters at decision height. The total score is a combination of the path and gate scores. The definitions of each of these measures is provided in the System Operations Manual (Logicon, 1974). A summary, however, will be presented.

Path Score. This measure defines performance on the glidepath as a function of deviations from glideslope, centerline, and optimum angle of attack. At each iteration deviations from glideslope and centerline are computed and categorized according to the vertical and horizontal zones shown in Figures A-1 and A-2. The basic measures are the percentages of time within each of the zones. Scoring is initiated at the time of glideslope intercept and terminates at either decision height or entry into any missed approach zone. The path score is computed according to the following formula:

$$\text{Path Score} = P_s = \frac{V_s + H_s + \alpha_s}{3} + T_s$$

where

$V_s = \%(OGP) + \frac{1}{2}[\%(SAGP) + \%(SBGP)]$

%(OGP) is the percentage of time the aircraft was in On Glidepath Zone.

%(SAGP) is the percentage of time the aircraft was in Slightly Above Gildepath Zone.

%(SBGP) is the percentage of time the aircraft was in Slightly Below Glidepath Zone.

$H_s = \%(He \leq 1) + \frac{1}{2}(1 < He < 5)$

%(He ≤ 1) is the percentage of time the aircraft heading was within 1 degree of assigned heading.

%(1<He≤5) is the percentage of time the aircraft heading was greater than 1 degree within 5 degrees of assigned heading

$\alpha_s = \%(18.1 < AOA < 20.3)$

Indicates the percentage of time the angle of attack was greater than 18.1 units but less than 20.3 units.

$T_s = 100\,(RAF)$

RAF is the Rough Air Factor, a number between 0 and 16. An Adjusted Path Score (P_{sa}) is computed, as follows, when the aircraft fails to penetrate the Gate at the decision height.

$$P_{sa} = L(P_s) + 100L$$

where

L = proportion of glidepath completed prior to termination.

P_s = path score as computed previously.

Gate Score. The gate score represents a "snapshot" look at performance at decision height. It is computed according to the following formula:

$$\text{Gate Score} = G_s = 1/3(Y_s + Z_s + A_s - \dot{\Psi}_n \dot{A}_s)$$

where

$Y_s = 100 - |Y_E|$

$|Y_E|$ is the absolute lateral error at the Gate (feet).

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$Z_s = 100 - |Z_E|$

$|Z_E|$ is the absolute vertical error at the Gate (feet).

$A_s = 100 - 25(|\alpha - 19.2|)$

$|\alpha - 19.2|$ is the absolute Angle of Attack error at the Gate (units).

$\dot{\Psi}_s = 25\ |\dot{A}|$

is the rate of change of heading at the Gate (deg/sec).

$\dot{A}_s = 25|\dot{A}|$

A is the rate of change of angle of attack at the Gate (units/sec).

Total Score. The total score is computed at the end of a trial and represents a combination of the Path and Gate scores. If the gate is reached, the following formula is used:

$$\text{Total Score} = P_s + G_s + 100$$

where

P_s = path score

G_s = gate score

In the event the gate is not reached, the total score is set equal to the adjusted path score, P_{sa}.

Additional Measures Several other measures were derived from parameters computed within the AFTS. The path score is probably the most reliable measure computed since it utilizes a large number of data points. Consequently, it seemed desirable to obtain measures on the three major parameters defining the path score deviations from glideslope, centerline, and optimum angle of attack. Throughout the training sorties, scores were computed for each of these parameters based on the percentages of time within the different zones. For the criterion sorties, the AFTS software was modified to provide more precise root-mean-square values. Also, the scoring was initiated at 7.5 miles from touchdown, rather than at the time of glideslope intersection. The formulas used are presented below.

Glideslope Score/RMS Glideslope Error. During the training sorties, the glideslope score was computed as follows:

$$\text{Glideslope Score} = \%(\text{OGP}) + \tfrac{1}{2}[\%(\text{SAGP}) + \%(\text{SBGP})]$$

where

%(OGP) is the percentage of time the aircraft was in On Glideslope Zone.

% (SAGP) is the percentage of time the aircraft was in Slightly Above Glidepath Zone.

% (SBGP) is the percentage of time the aircraft was in Slightly Below Glidepath Zone.

The RMS Glideslope Error score used during the criterion sorties was computed as follows:

$$\sqrt{\frac{\sum_{i=1}^{N} (\alpha i)^2}{N}}$$

where

αi = glideslope angle error in sample i

N = number of samples

Course Angle Score/RMS Course Angle Error. The course angle score was computed as follows:

$$\text{Course Angle Score} = \%(OC) + \tfrac{1}{2}[\%(SCR) + \%(SLC)]$$

where

% (OC) is the percentage of time the aircraft was in On Course Zone

% (SRC) is the percentage of time the aircraft was in Slightly Right of Course Zone

% (SLC) is the percentage of time the aircraft was in Slightly Left of Course Zone

The RMS Course Angle Error score was computed as follows:

$$\sqrt{\frac{\sum_{i=1}^{N} (\alpha i)^2}{N}}$$

where

αi = Course angle error on sample i

N = Number of samples

Path Completion Score. Each GCA for both the training and criterion sorties was scored according to whether or not the path was completed; that is, whether decision height was reached. A successful completion was scored 1, a non-completion, 0.

Adaptive Scheduling

The AFTS adaptive scheduling program functioned in the following manner: After the first trial by the student pilot, his total score for the run was used in the adaptive scheduling logic to determine the appropriate difficulty level for the next trial. Table A1 shows the factors which were used to adjust difficulty level for each student

Table A1. **Difficulty Level Adjustment Values**

Previous Run's Step Number Adjustment Status	Scoring Range (S represents Total Score)				
	S<50	50≤S<100	100≤S<150	150≤S<200	200≤S
	Adjustment Factors to be added to, no change, or subtracted from previous run's Step number				
− (Decremented)	−3	−2	0	0	+1
0 (No Change)	−2	−1	+1	+1	+2
+ (Incremented)	−1	0	+1	+2	+3

The difficulty level for each run was based on the total score of the previous run, and whether the previous run had been decremented, unchanged, or incremented. For example, suppose that a student was just starting out using the GCA adaptive scheduling program and that he received scores of 120, 150 and 200. Since the student has not used the system previously, then the system has no record of incrementing or decrementing the student. Therefore, if it is assumed that the student started at Difficulty Level 1, then a score of 120 will result in an increment of +1 (enter table for 0-no change and score between 100 and 150). The second trial will be at Difficulty Level 2. For this trial, the student received a score of 150. Since the program logic now has a record of the student showing that he was incremented, the Difficulty Level for

the student will be incremented by +2 steps. The third trial will be performed at Difficulty Level 4. At the completion of this trial, the score of 200 is examined for the instance where the previous run difficulty level has been incremented. In this instance, the Difficulty Level for the student would be incremented +3 steps. Thus, the fourth trial would be conducted at Difficulty Level 7. The AFTS program logic kept track of all students in the program so that the student always started at the Difficulty Level where he had stopped (even though several days might elapse before his next training period). If the student had problems in training, then the Difficulty Level of the trials would be adjusted downward to compensate for his lack of skill.

GCA Difficulty Levels

Difficulty was introduced into the GCA trial by automatically varying winds (direction and speed), aircraft weight, atmospheric turbulence, and aircraft emergencies. The initial layout of the Difficulty Levels was accomplished through the efforts of Logicon and the F-4 Instructional System Development Team (ISDT). The ordering of the levels was based upon analytical examination and required empirical verification.

1. *Wind Direction and Speed.* Wind direction relative to the runway heading (210) was varied as follows:

Code	Wind Direction/Speed	Code	Wind Direction/Speed
0	210/35 kt	5	120/10 kt
1	210/20 kt	6	300/20 kt
2	210/10 kt	7	120/20 kt
3	Calm	8	030/10 kt
4	300/10 kt	9	030/20 kt

2. *Aircraft Weight.* Aircraft weight and drag was varied by changing the internal fuel load. The following weights were investigated:

Code	Aircraft Weight
0	35,000
1	38,000
2	41,000
3	43,700
4–9	Reserved for future expansion

3. *Turbulence.* The wind turbulence factors affecting flight performance along the glideslope were:

Code	Turbulence Characteristic
0	None
1	Light
2	Moderate
3	Heavy
4–9	Reserved for future expansion

The heavy turbulence that was used was 16 percent of the maximum amount of turbulence that was available in the simulator.

4. *Aircraft Emergencies.* The type of malfunction and the point at which the malfunction occurred from touchdown are shown in the following list:

Code	Emergency	Distance From Touchdown
00	None	--
01	Utility hydraulic failure	10 miles
02	Flap failure	10 miles
03	Left engine failure	8 miles
04	Right engine failure	2 miles
05	Stab 2 aug failure	10 miles
06	No gyro approach procedure, no MIDU failures	--
07	ASR approach	--
08	Ins and AN/AJB-7 failure. No gyro procedure	10 miles
09	Communications failure (receiver)	3 miles
10–32	Reserved for future expansion	--

Table A2 shows the 76 Difficulty Levels that were available in the AFTS. As shown in the table, wind was varied initially (difficulty levels 1–10); then weight and wind variables were varied (Difficulty Levels 11 through 20); turbulence, aircraft weight, and wind were varied for the next ten levels (Difficulty Levels 21 through 30). Starting with Difficulty Level 31, aircraft emergencies or degraded GCA approaches were introduced in combination with wind, aircraft weight, and atmospheric turbulence variables.

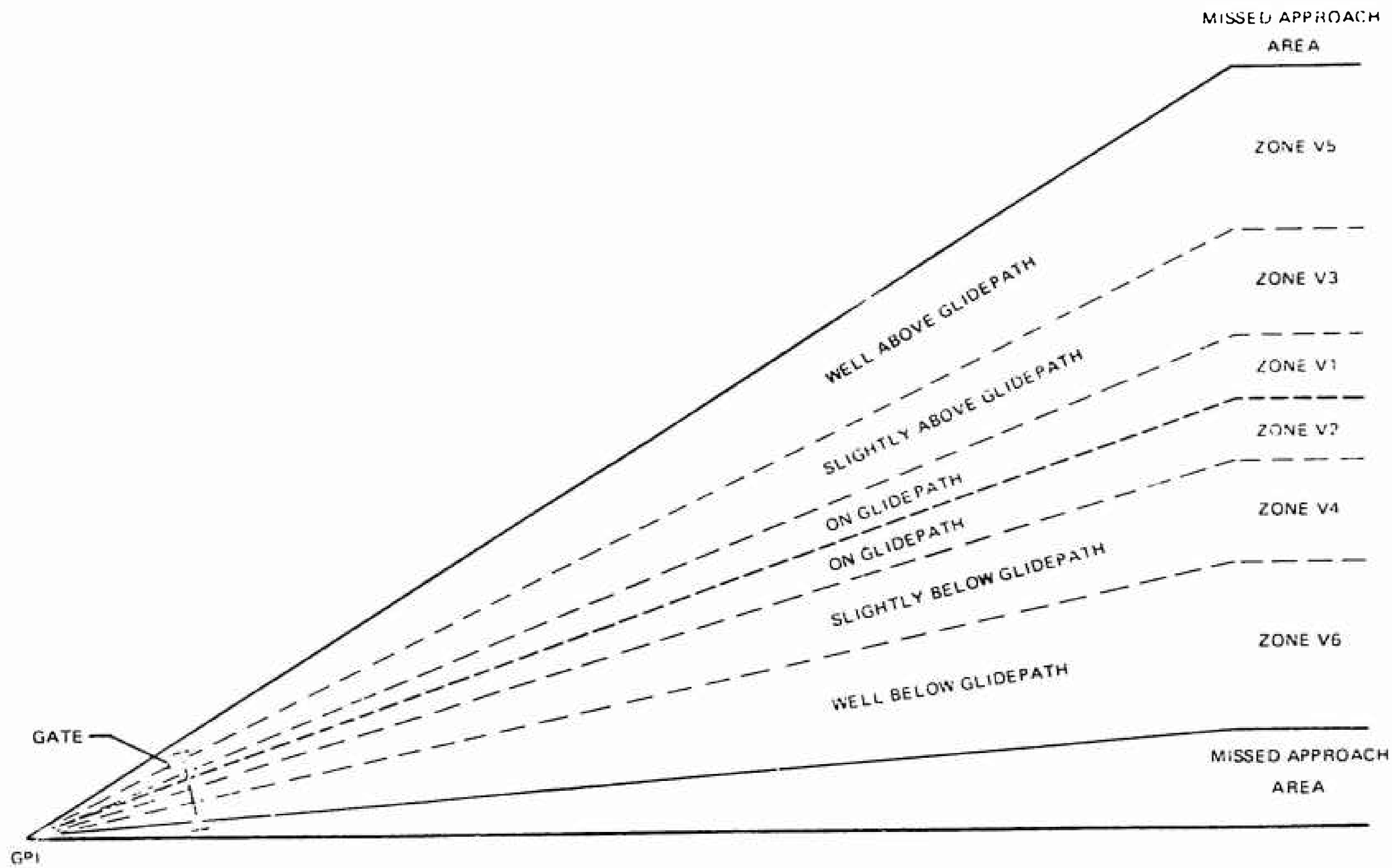

Figure A1. **Vertical glideslope zones.**

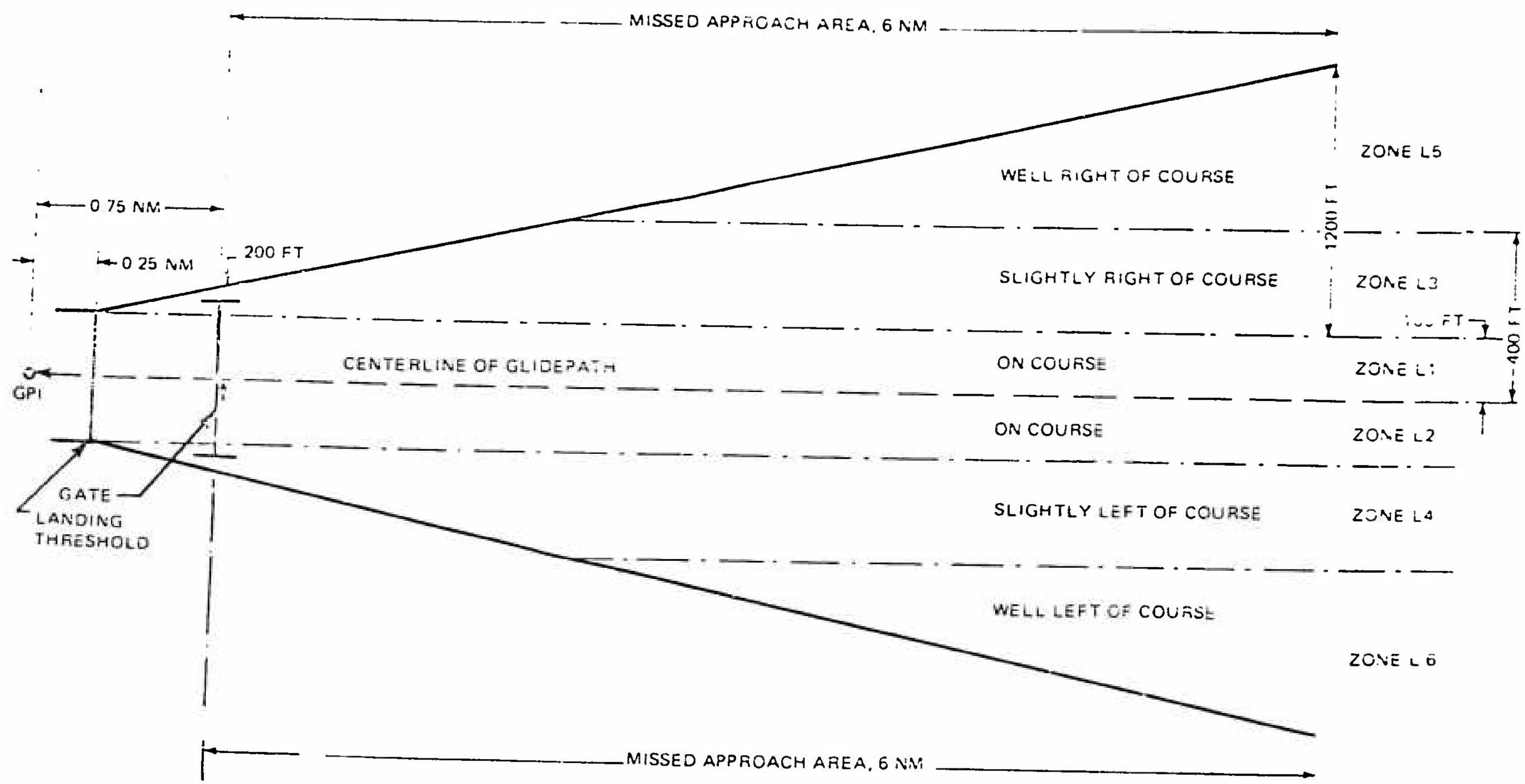

Figure A2. **Approach course zones.**

Table A2. **Mode 1 GCA Syllabus**

Step	Emergency	Turbulence	Weight	Wind Direction	Wind Speed	Difficulty Levels[1] E	Difficulty Levels[1] TWV
WIND							
1	None	None	35,000	210	25	00	000
2	None	None	35,000	210	20	00	001
3	None	None	35,000	210	10	00	002
4	None	None	35,000	210	0	00	003
5	None	None	35,000	300	10	00	004
6	None	None	35,000	120	10	00	005
7	None	None	35,000	300	20	00	006
8	None	None	35,000	120	20	00	007
9	None	None	35,000	030	10	00	008
10	None	None	35,000	030	20	00	009
WEIGHT							
11	None	None	38,000	210	35	00	010
12	None	None	41,000	210	35	00	020
13	None	None	43,700	210	35	00	030
14	None	None	43,700	210	0	00	033
15	None	None	43,700	300	10	00	034
16	None	None	38,000	120	10	00	015
17	None	None	41,000	120	20	00	027
18	None	None	38,000	030	10	00	018
19	None	None	41,000	030	20	00	029
20	None	None	43,700	030	20	00	039
TURBULENCE							
21	None	Light	35,000	210	35	00	100
22	None	Moderate	35,000	210	35	00	200
23	None	Heavy	35,000	210	35	00	300
24	None	Light	35,000	300	10	00	104
25	None	Moderate	41,000	120	10	00	225
26	None	Light	41,000	300	20	00	126
27	None	Moderate	41,000	120	20	00	227
28	None	Moderate	41,000	030	20	00	229
29	None	Heavy	41,000	030	20	00	329
30	None	Heavy	43,700	030	20	00	3[illegible]

Note 1. E represents emergencies; T, turbulence; W, aircraft weight; and V, wind direction and speed. A-12

Table A2 (*Continued*)

Step	Emergency	Turbulence	Weight	Wind Direction	Wind Speed	Difficulty Levels[1] E	Difficulty Levels[1] TWV
UTILITY HYDRAULIC FAILURES							
31	01	None	35,000	210	25	01	000
32	01	Light	38,000	300	10	01	114
33	01	Light	38,000	120	20	01	117
34	01	Moderate	41,000	030	20	01	229
35	01	Heavy	43,700	030	20	01	339
FLAP FAILURE							
36	02	None	35,000	210	35	02	000
37	02	Light	38,000	300	10	02	114
38	02	Light	38,000	120	20	02	117
39	02	Moderate	41,000	030	20	02	229
40	02	Heavy	43,700	030	20	02	339
SINGLE ENGINE FAILURE							
41	03	None	35,000	210	35	03	000
42	04	None	35,000	210	35	04	000
43	03	Light	38,000	300	10	03	114
44	04	Light	38,000	300	10	04	114
45	03	Light	38,000	120	20	03	117
46	04	Light	38,000	120	20	04	117
47	03	Moderate	41,000	030	20	03	229
48	04	Moderate	41,000	030	20	04	229
49	03	Heavy	43,700	030	20	03	339
50	04	Heavy	43,700	030	20	04	339
STAB 1 AUG FAILURE							
51	05	None	35,000	210	35	05	000
52	05	Light	38,000	300	10	05	114
53	05	Light	38,000	120	20	05	117
54	05	Moderate	41,000	030	20	05	229
55	05	Heavy	43,700	030	20	05	339

Note 1. E represents emergencies; T, turbulence; W, aircraft weight; and V, wind direction and speed.

Table A2 (*Continued*)

Step	Emergency	Turbulence	Weight	Wind Direction	Wind Speed	Difficulty Levels [1] E	Difficulty Levels [1] TWV
NO GYRO APPROACH							
56	06	None	35,000	210	35	06	000
57	06	Light	38,000	300	10	06	114
58	06	Light	38,000	120	20	06	117
59	06	Moderate	41,000	030	20	06	229
60	06	Heavy	43,700	030	20	06	339
ASR APPROACH							
61	07	None	35,000	210	35	07	000
62	07	None	35,000	210	0	07	003
63	07	Moderate	43,700	210	0	07	233
64	07	Light	41,000	300	10	07	124
65	07	Moderate	43,700	120	10	07	235
66	07	Light	41,000	300	20	07	126
67	07	Moderate	43,700	120	20	07	237
68	07	Light	38,000	030	10	07	118
69	07	Light	41,000	030	20	07	129
70	07	Moderate	43,700	030	20	07	239
INS & AN/AJB-7 FAILURE							
71	08	None	35,000	210	35	08	000
72	08	Light	38,000	300	10	08	114
73	08	Light	38,000	120	20	08	117
74	08	Moderate	41,000	030	20	08	229
75	08	Heavy	43,700	030	20	08	339
COMMUNICATIONS FAILURE							
76	09	Light	38,000	120	20	09	117

Note 1. E represents emergencies; T, turbulence; W, aircraft weight; and V, wind direction and speed.

Table B1. **Mean Difficulty Levels for the Adaptive Group as a Function of Training Trials**

Trial	Mean	SD
1	1.0000	0.0000
2	1.5000	0.6455
3	1.7500	0.8292
4	2.4167	1.3819
5	3.5833	2.2158
6	5.0833	3.1480
7	6.8333	3.8261
8	7.9167	4.3677
9	9.3333	5.0056
10	11.0000	6.0000
11	13.0000	6.6081
12	15.2500	7.4288
13	17.0000	7.2572
14	18.7500	7.5512
15	20.3333	7.9408
16	22.5000	8.1803
17	24.5833	8.4406
18	25.5000	8.6939
19	27.3333	9.2766
20	28.6667	9.2586
21	30.1667	9.0722
22	31.8333	8.8867
23	33.3333	8.9287
24	34.6667	9.0860
25	36.0000	9.0921
26	37.2500	9.1845
27	37.8333	9.6336
28	39.1667	9.8474
29	41.0833	10.6963
30	42.4167	11.6580
31	44.7500	12.1595
32	46.8333	12.6809

Table B2. **Mean Path Completion as a Function of Training Blocks**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	.208	.246	.136	.308
2	.444	.343	.409	.313
3	.541	.313	.545	.294
4	.778	.343	.788	.294
5	.736	.250	.727	.278
6	.695	.253	.727	.278
7	.708	.237	.621	.390
8	.667	.297	.545	.403
9	.500	.319	.606	.269
10	.611	.299	.697	.332
11	.722	.266	.758	.250
Total	.601	.331	.596	.362

See Table B16 for sample sizes.

Table B3. **Mean Glideslope Score as a Function of Training Blocks**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	47.40	12.16	45.02	11.50
2	52.85	12.36	56.37	11.36
3	57.35	12.72	61.54	8.05
4	68.36	11.69	62.42	16.11
5	63.45	8.01	67.74	13.91
6	55.73	11.18	67.19	14.08
7	55.63	16.51	59.72	18.68
8	57.37	16.99	61.52	13.80
9	56.55	12.27	56.62	18.21
10	62.43	13.48	60.82	8.14
11	57.53	11.80	57.28	7.94
Total	57.696	13.915	59.659	14.636

Table B4. **Mean Course Angle Score as a Function of Training Blocks**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	53.56	20.19	58.28	21.07
2	60.51	17.61	64.31	16.20
3	63.08	13.13	65.43	13.57
4	74.20	11.68	74.98	11.05
5	68.01	13.15	65.32	11.69
6	59.45	8.86	69.55	17.18
7	66.17	14.76	62.75	24.26
8	75.41	16.80	63.85	17.00
9	53.90	20.83	68.27	11.06
10	64.05	18.88	67.43	16.53
11	72.42	9.49	69.21	11.89
Total	63.706	16.788	66.307	16.643

Table B5. **Mean Angle of Attack Score as a Function of Training Block**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	19.75	12.19	19.56	12.75
2	22.53	15.52	25.01	13.94
3	31.78	14.40	28.85	16.34
4	40.31	18.57	35.80	16.58
5	32.11	11.02	35.61	16.10
6	25.66	15.19	30.11	23.77
7	26.68	12.28	29.84	17.91
8	33.84	13.46	30.70	13.03
9	23.87	15.67	26.81	12.31
10	37.25	16.29	21.34	13.99
11	34.18	14.37	27.33	13.64
Total	29.816	15.870	28.269	16.536

Table B6. **Mean Path Score as a Function of Training Block**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	42.52	11.92	43.01	10.29
2	47.07	13.37	51.32	9.76
3	53.74	10.43	54.16	9.88
4	65.65	10.44	62.38	12.21
5	61.46	10.53	63.00	11.01
6	54.14	8.59	62.69	14.46
7	59.48	11.53	61.41	15.12
8	61.25	11.93	60.63	11.30
9	54.56	15.17	60.57	10.75
10	65.51	12.85	59.62	10.09
11	64.69	9.35	61.38	11.64
Total	57.280	13.696	58.203	13.062

Table B7. **Mean Gate Score as a Function of Training Block**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	2.30	16.08	3.43	13.06
2	18.35	22.05	13.33	16.50
3	25.49	19.14	24.98	13.47
4	33.77	27.11	42.49	20.99
5	27.19	20.61	31.65	12.74
6	25.76	10.81	25.15	29.07
7	27.02	18.88	32.51	24.86
8	28.10	21.69	28.76	22.80
9	20.74	26.47	27.08	16.32
10	27.71	18.94	30.26	15.07
11	35.05	24.68	27.68	17.10
Total	24.681	22.690	26.120	21.447

Table B8. **Mean Total Score as a Function of Training Blocks**

Training Block	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1	93.57	43.37	88.51	41.06
2	139.29	49.18	125.64	45.24
3	161.28	38.42	154.50	34.10
4	192.47	44.81	194.79	42.06
5	171.87	38.83	179.34	43.07
6	173.00	22.99	170.11	55.52
7	168.17	39.48	168.40	68.50
8	171.68	41.49	168.70	50.38
9	148.50	60.96	168.72	31.73
10	181.64	36.71	168.18	39.84
11	189.77	39.88	183.18	25.81
Total	162.800	50.069	161.098	52.998

Table B9. **Selected Descriptive Statistics for Path Completion Data Collected During Criterion Sorties**

Category**	Adaptive		Control	
	$\bar{X}$	SD	$\bar{X}$	SD
1st Sortie	.875	.331	.803	.398
2nd Sortie	.847	.360	.758	.429
GCA Controller	.861	.346	.803	.398
AFTS Controller	.861	.346	.758	.429
Level 1	.979	.143	.886	.317
Level 30	.896	.306	.841	.366
Level 49	.708	.455	.614	.487
Total	.861	.346	.780	.414

**See Table B17 for sample sizes.

Table B10. **Selected Descriptive Statistics for RMS Glideslope Error Data Collected During Criterion Sorties**

Category	Adaptive		Control	
	$\bar{X}$	SD	$\bar{X}$	SD
1st Sortie	.269	.167	.259	.164
2nd Sortie	.273	.172	.272	.137
GCA Controller	.236	.124	.247	.138
AFTS Controller	.302	.199	.284	.161
Level 1	.216	.081	.212	.077
Level 30	.205	.089	.211	.080
Level 49	.286	.225	.373	.196
Total	.269	.169	.265	.151

Table B11. **Selected Descriptive Statistics for RMS Course Angle Error Data Collected During Criterion Sorties**

Category	Adaptive		Control	
	$\bar{X}$	SD	$\bar{X}$	SD
1st Sortie	.406	.289	.377	.264
2nd Sortie	.395	.315	.366	.238
GCA Controller	.339	.335	.299	.219
AFTS Controller	.462	.251	.444	.260
Level 1	.302	.214	.264	.188
Level 30	.345	.287	.299	.173
Level 49	.555	.331	.551	.275
Total	.401	.302	.371	.251

Table B12. **Selected Descriptive Statistics for RMS Angle of Attack Error Data Collected During Criterion Sorties**

Category	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1st Sortie	1.676	.654	1.787	.761
2nd Sortie	1.971	1.078	1.981	.763
GCA Controller	1.895	.968	1.874	.786
AFTS Controller	1.752	.829	1.895	.750
Level 1	1.653	.788	1.820	.852
Level 30	1.758	.708	1.918	.853
Level 49	2.060	1.113	1.916	.557
Total	1.824	.904	1.885	.768

Table B13. **Selected Descriptive Statistics for Path Score Data Collected During Criterion Sorties**

Category	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1st Sortie	76.955	15.935	75.982	15.923
2nd Sortie	75.154	16.501	74.889	14.485
GCA Controller	79.650	14.467	80.677	14.266
AFTS Controller	72.481	17.113	70.194	14.335
Level 1	71.740	14.331	70.357	15.466
Level 30	86.158	13.090	84.543	13.008
Level 49	70.298	16.162	71.407	12.751
Total	76.065	16.249	75.436	15.231

Table B14. **Selected Descriptive Statistics for Gate Score Data Collected During Criterion Sorties**

Category	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1st Sortie	46.992	28.354	44.600	29.733
2nd Sortie	47.958	28.306	38.559	28.918
GCA Controller	48.251	28.767	44.974	31.450
AFTS Controller	46.699	27.873	38.185	26.952
Level 1	54.098	26.550	31.555	25.260
Level 30	54.575	24.542	41.736	29.891
Level 49	33.752	28.613	31.448	29.565
Total	47.475	28.334	41.580	29.484

Table B15. **Selected Descriptive Statistics for Total Score Data Collected During Criterion Sorties**

Category	Adaptive $\bar{X}$	Adaptive SD	Control $\bar{X}$	Control SD
1st Sortie	218.960	49.220	213.956	51.496
2nd Sortie	216.796	49.733	204.744	51.913
GCA Controller	221.413	51.102	218.723	53.757
AFTS Controller	214.343	47.560	199.977	48.205
Level 1	225.335	37.197	217.207	46.880
Level 30	233.736	51.779	219.221	53.395
Level 49	194.562	49.316	191.623	50.614
Total	217.878	49.489	209.350	51.910

Table B16. **Sample Sizes for Training Block Data**

Block	Adaptive	Control
1	12	11
2	12	11
3	12	11
4	12	11
5	12	11
6	12	11
7	12	11
8	12	11
9	12	11
10	12	11
11	12	11
Total	132	121

Table B17. **Sample Sizes for Criterion Sortie Data**

Category	Adaptive	Control
1st Sortie	72	66
2nd Sortie	72	66
GCA Controller	72	66
AFTS Controller	72	66
Level 1	48	44
Level 30	48	44
Level 49	48	44
Total	144	132

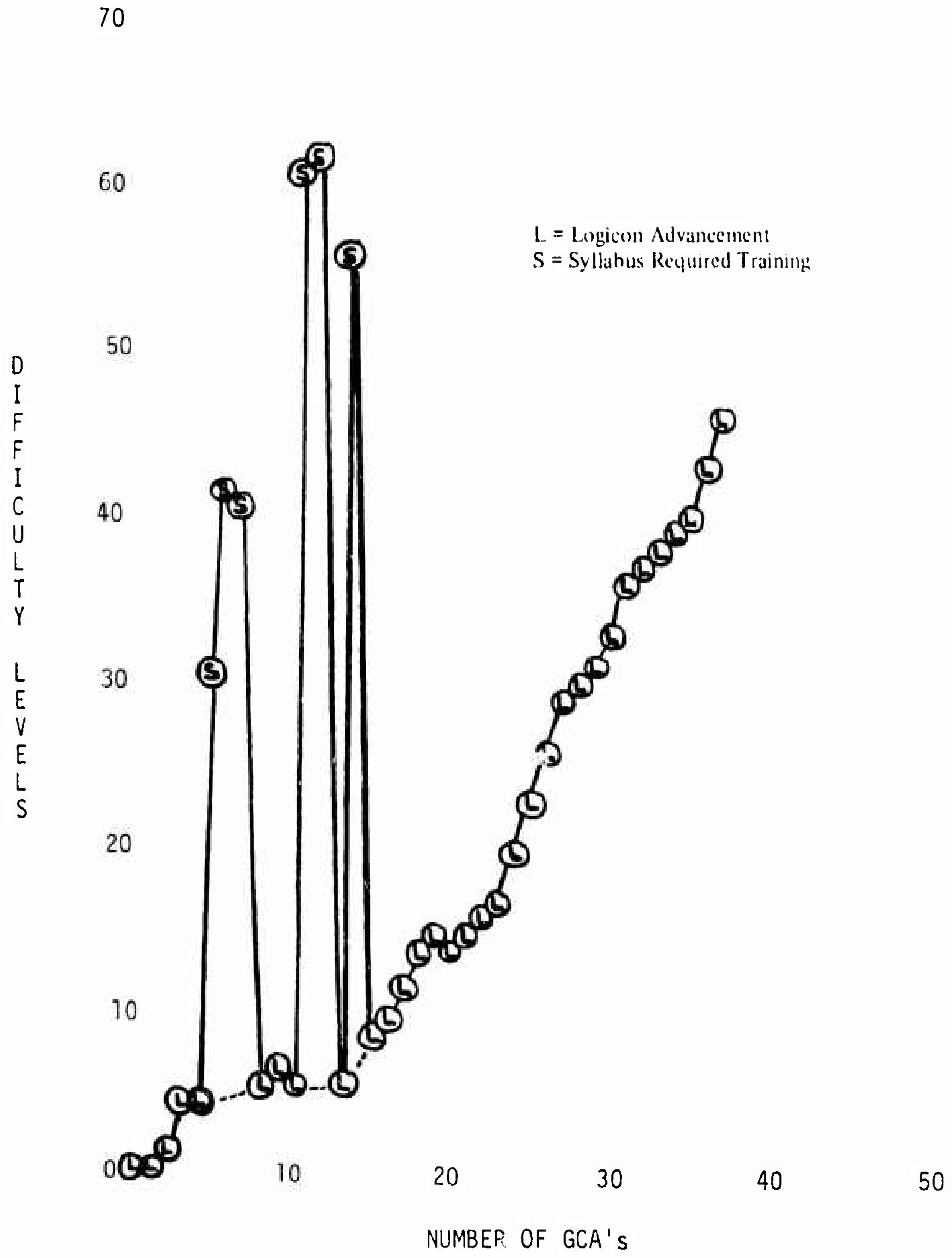

Figure B1. **Difficulty levels achieved by student 1A.**

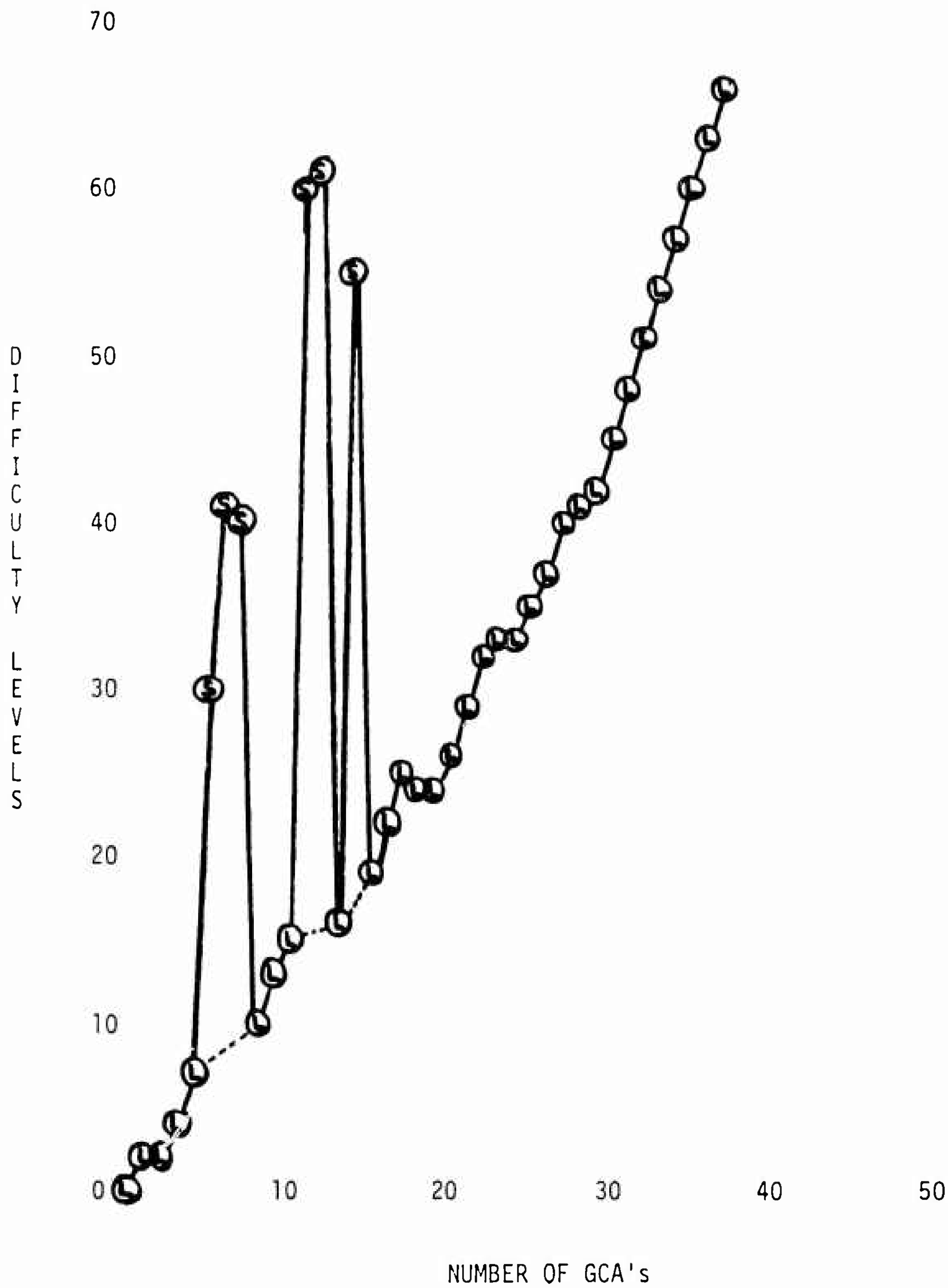

Figure B2. **Difficulty levels achieved by student 2A.**

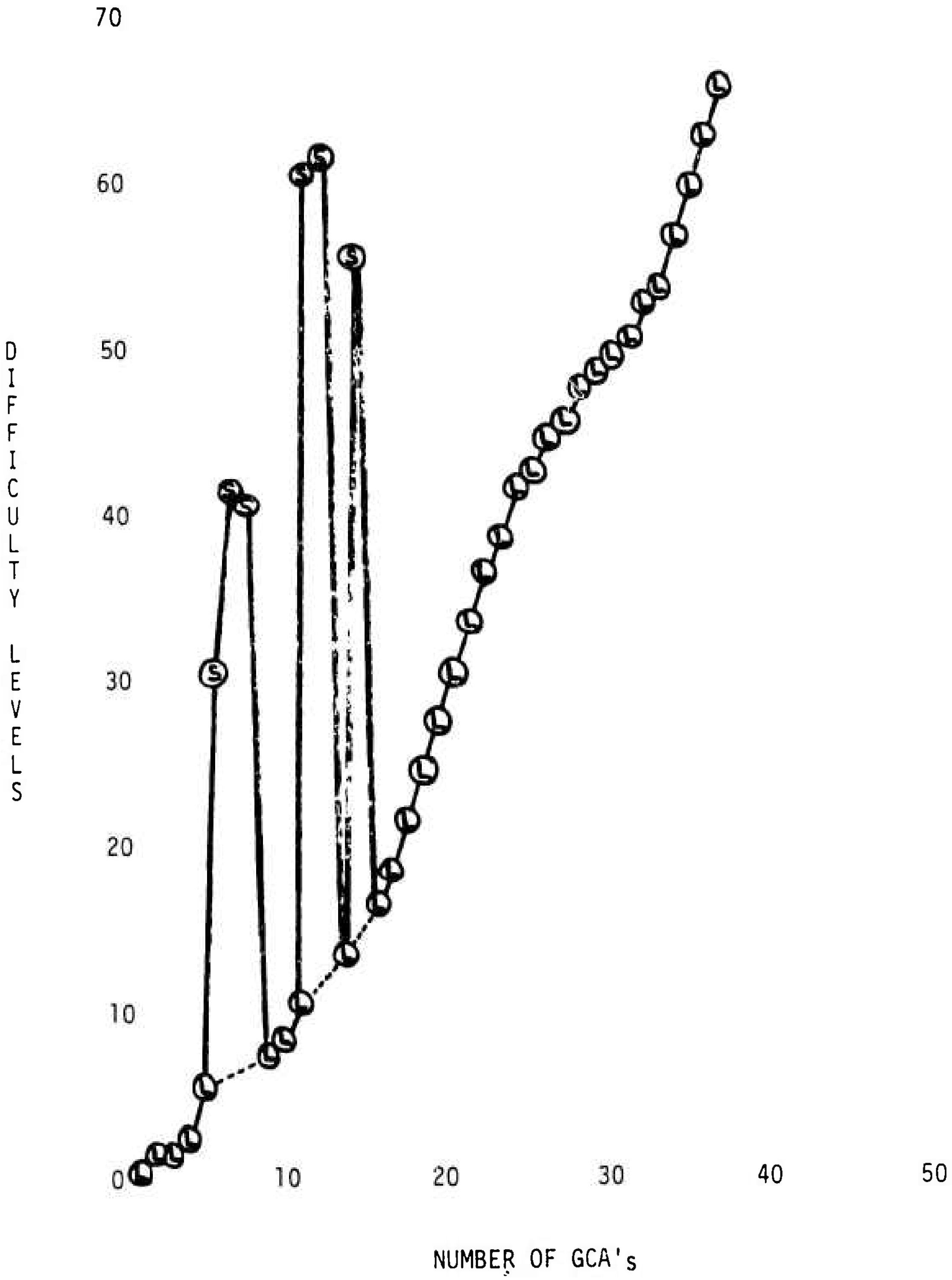

Figure B3. **Difficulty levels achieved by student 3A.**

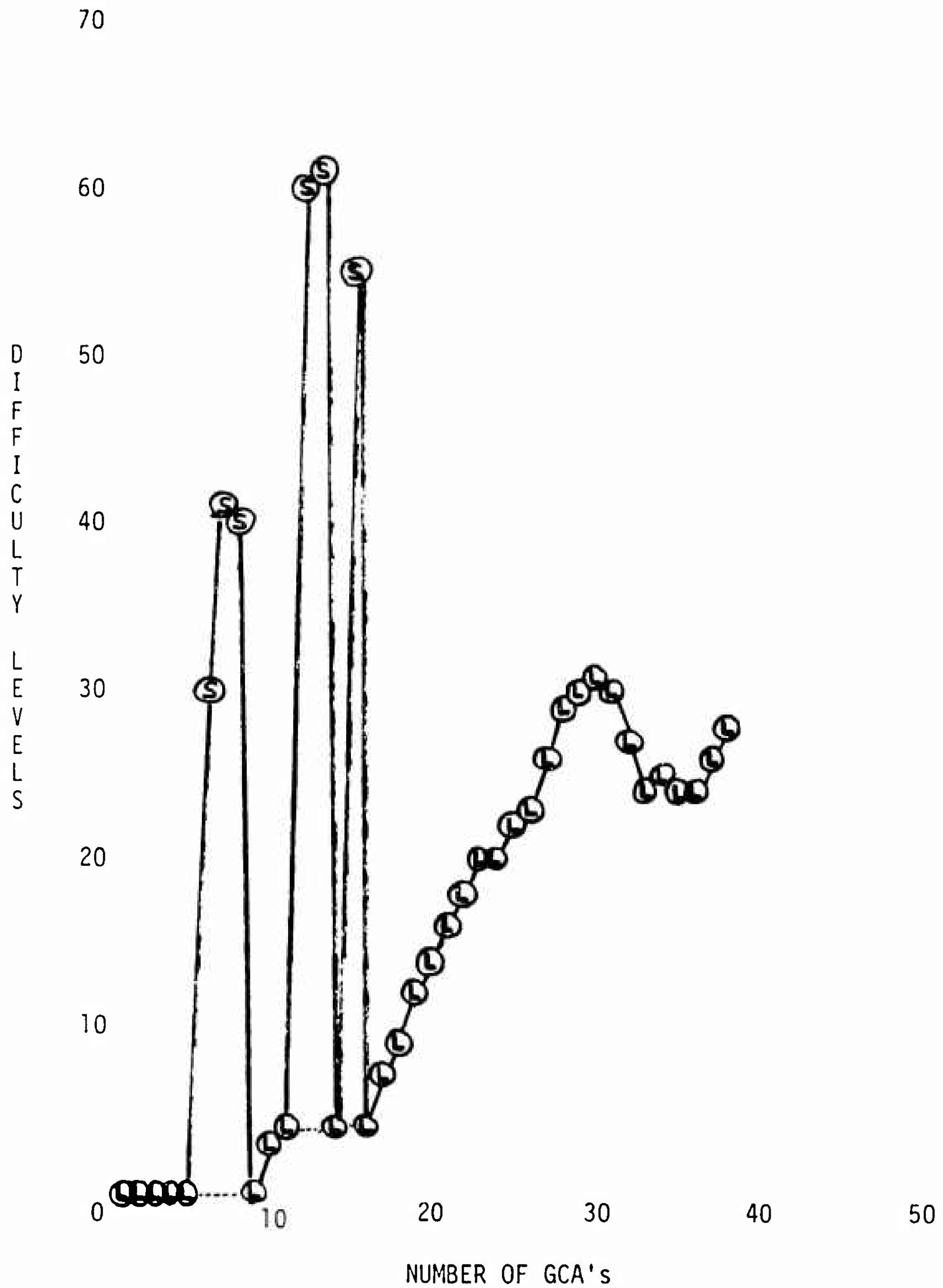

Figure B4. **Difficulty levels achieved by student 4A.**

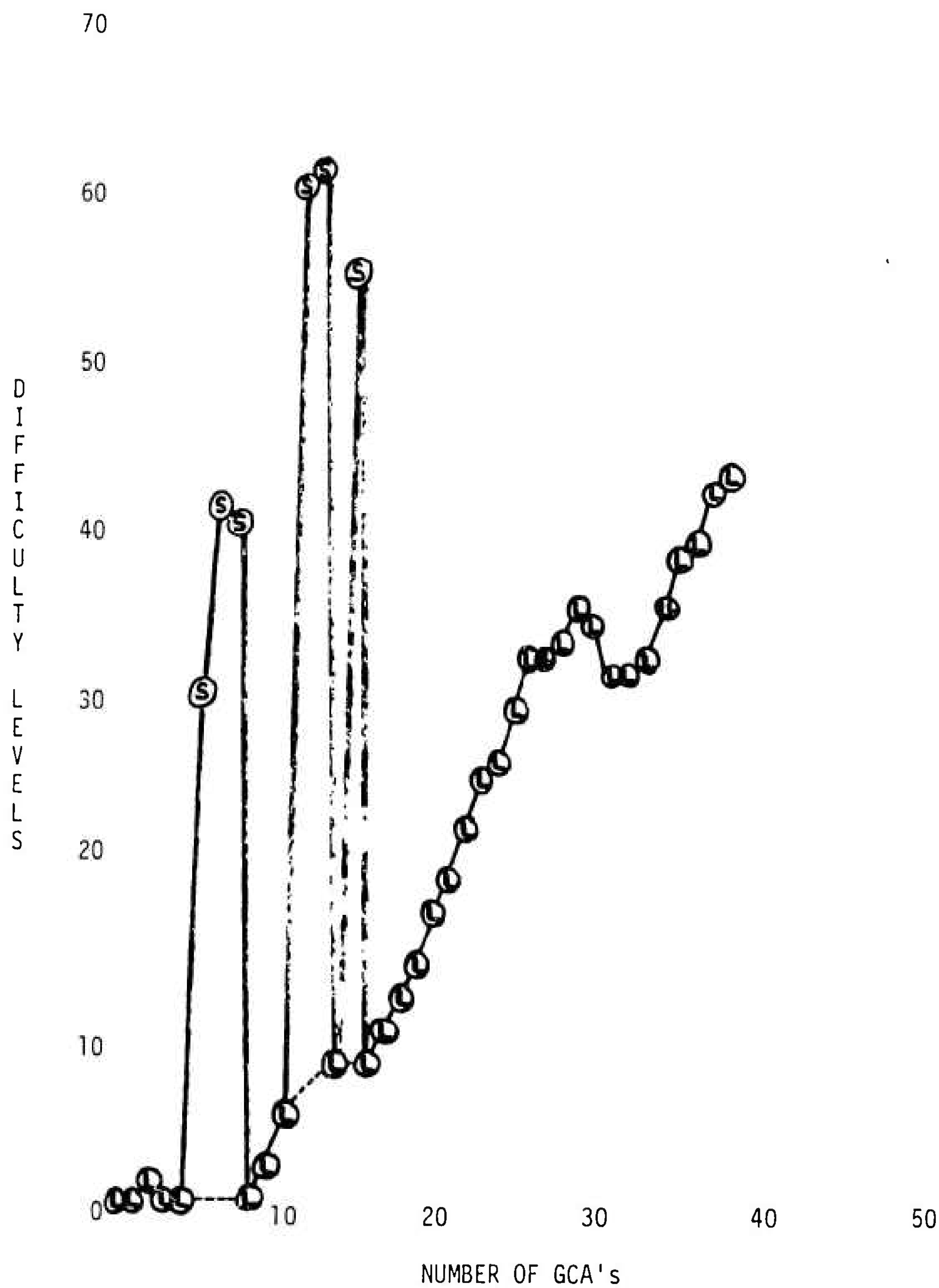

Figure B5. **Difficulty leve s achieved by student 5A.**

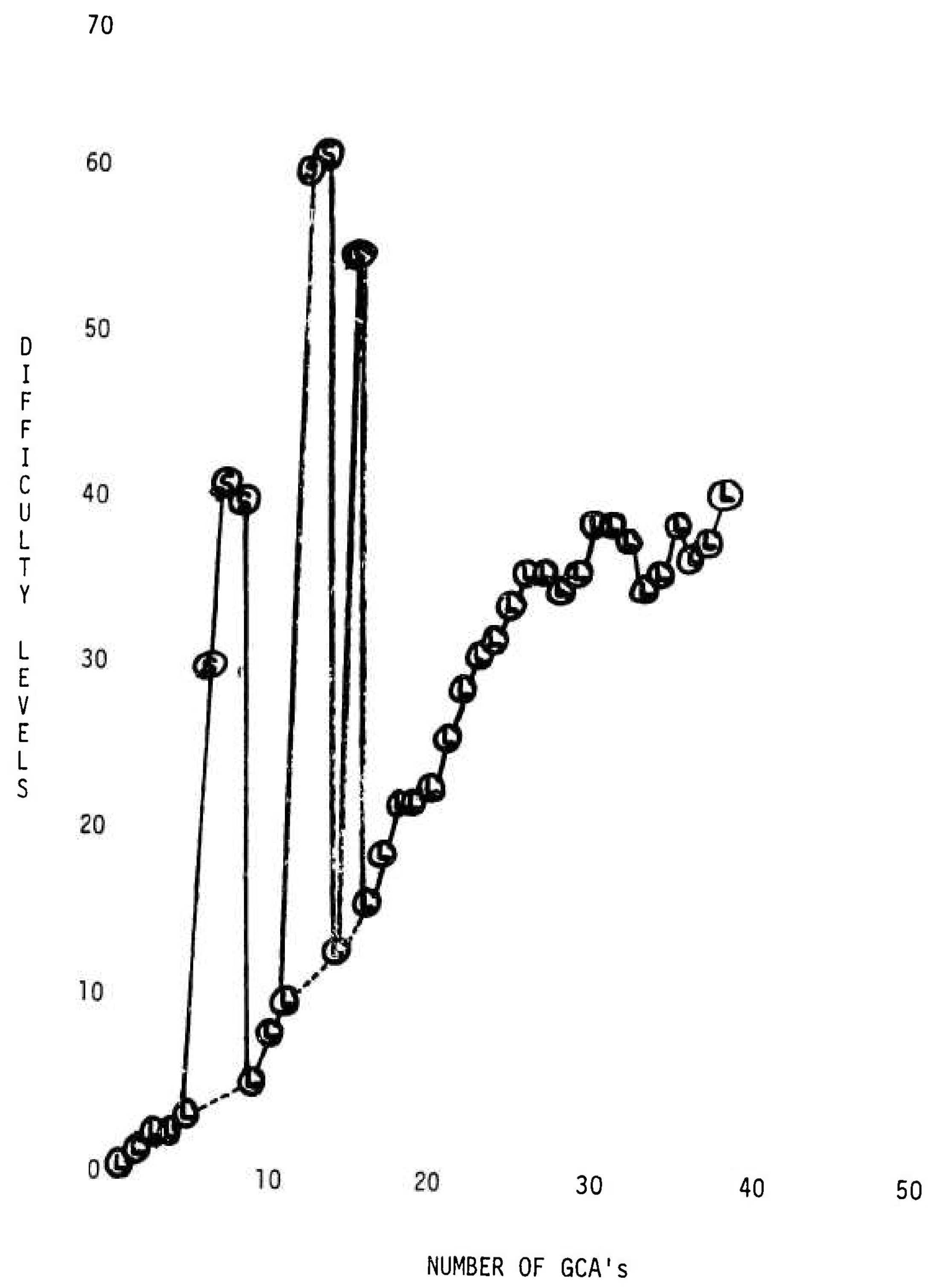

Figure B6. **Difficulty levels achieved by student 6A.**

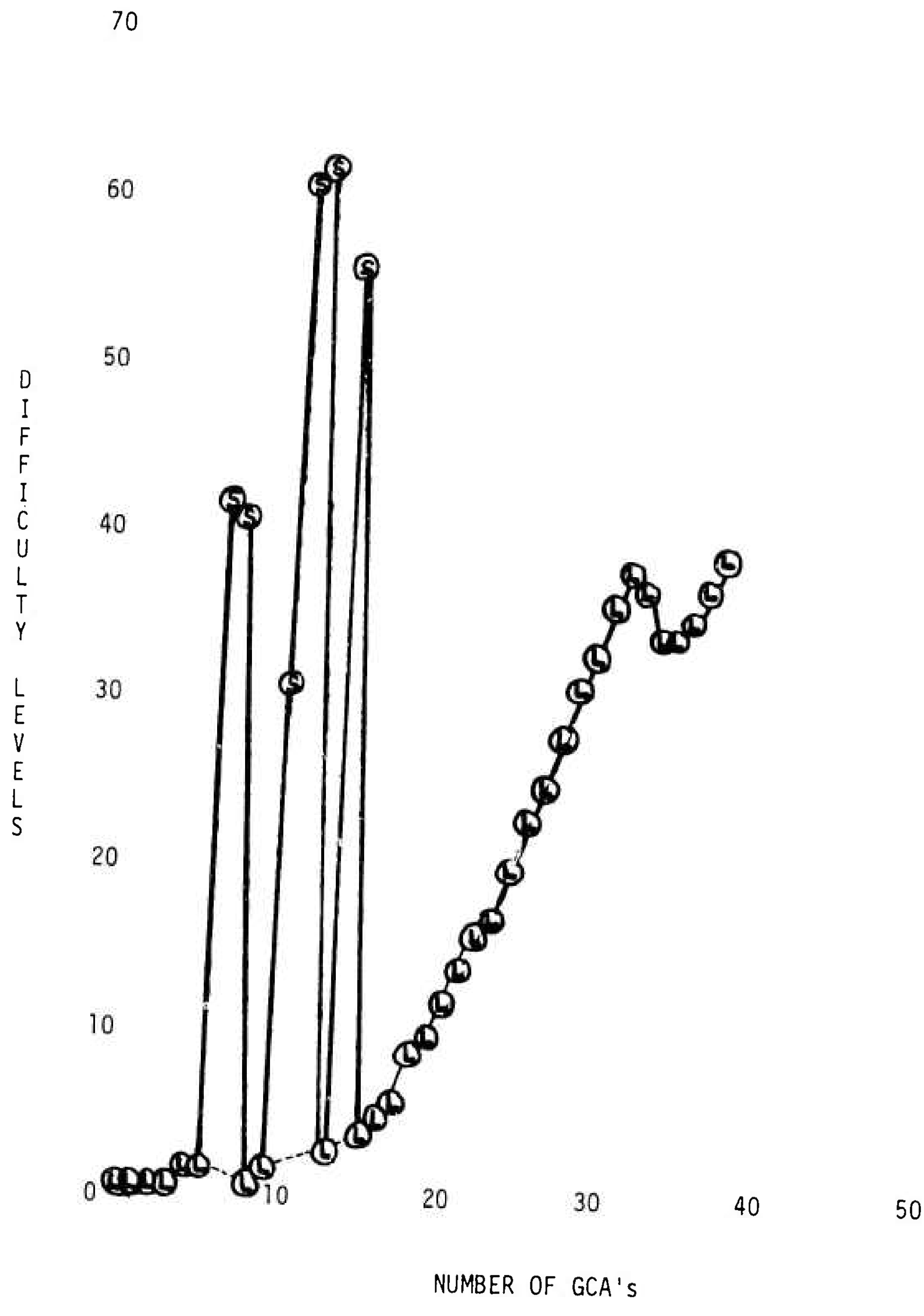

Figure B7. **Difficulty levels achieved by student 7A.**

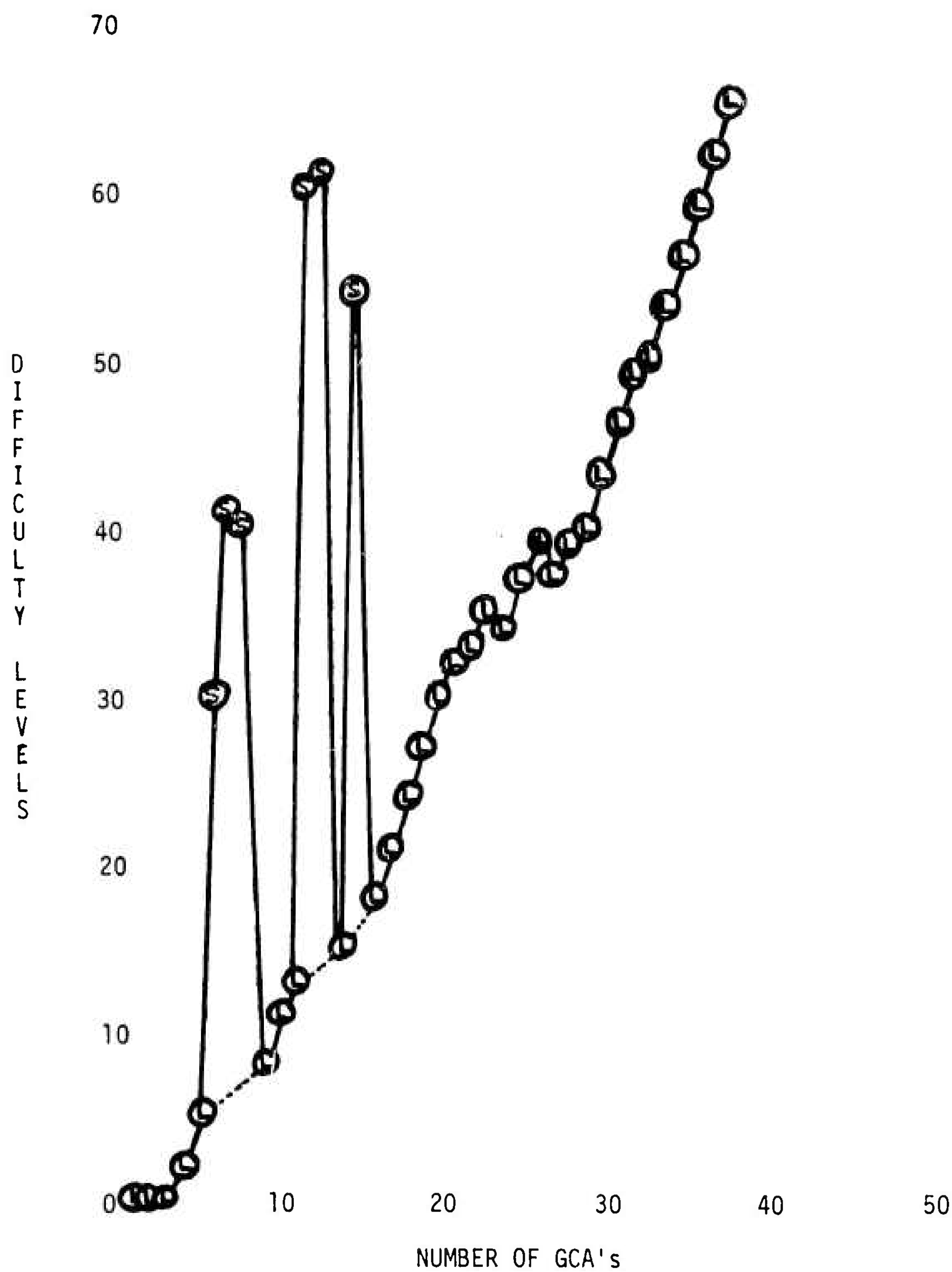

Figure B8. **Difficulty levels achieved by student 8A.**

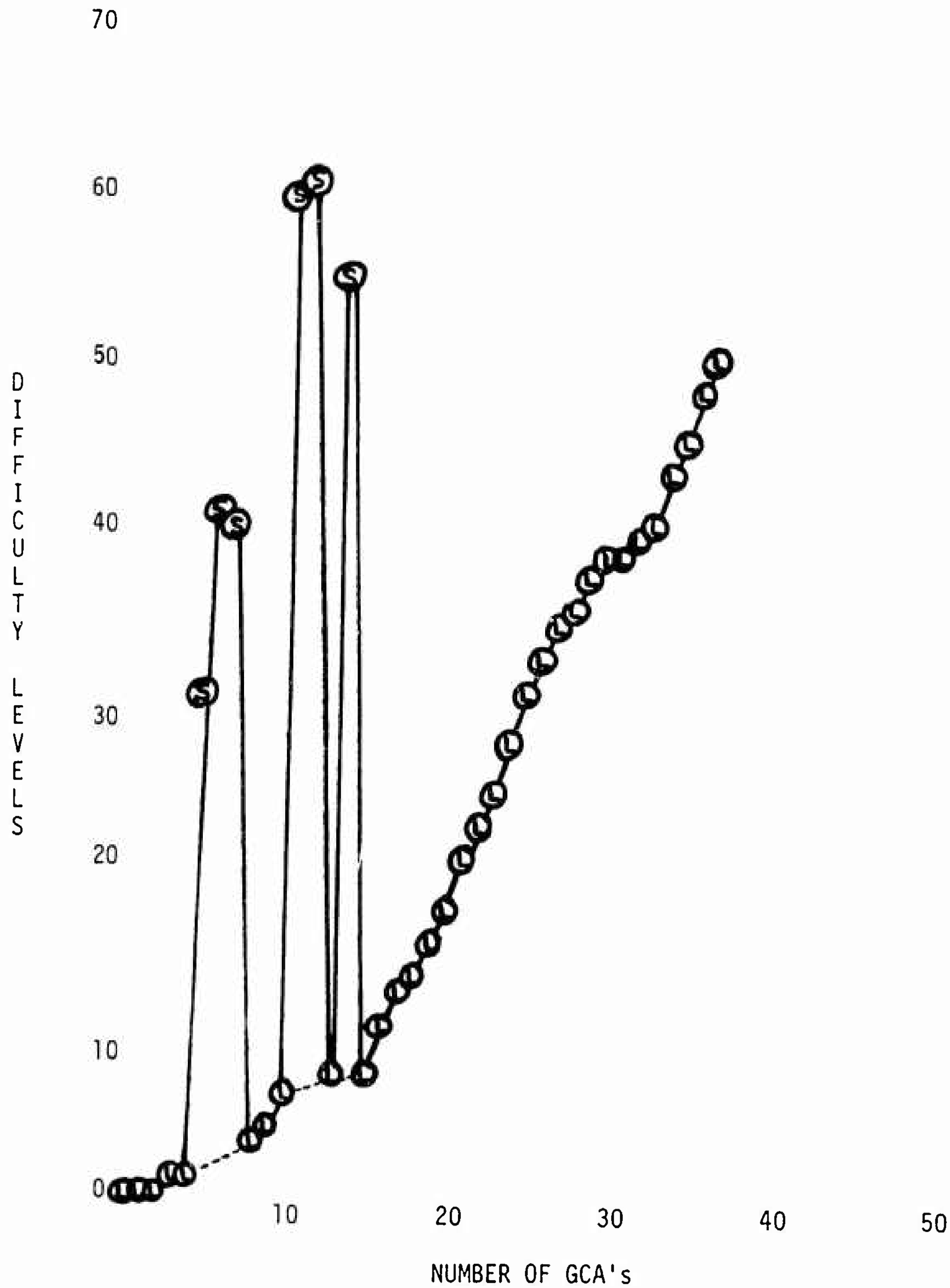

Figure B9. **Difficulty levels achieved by student 9A.**

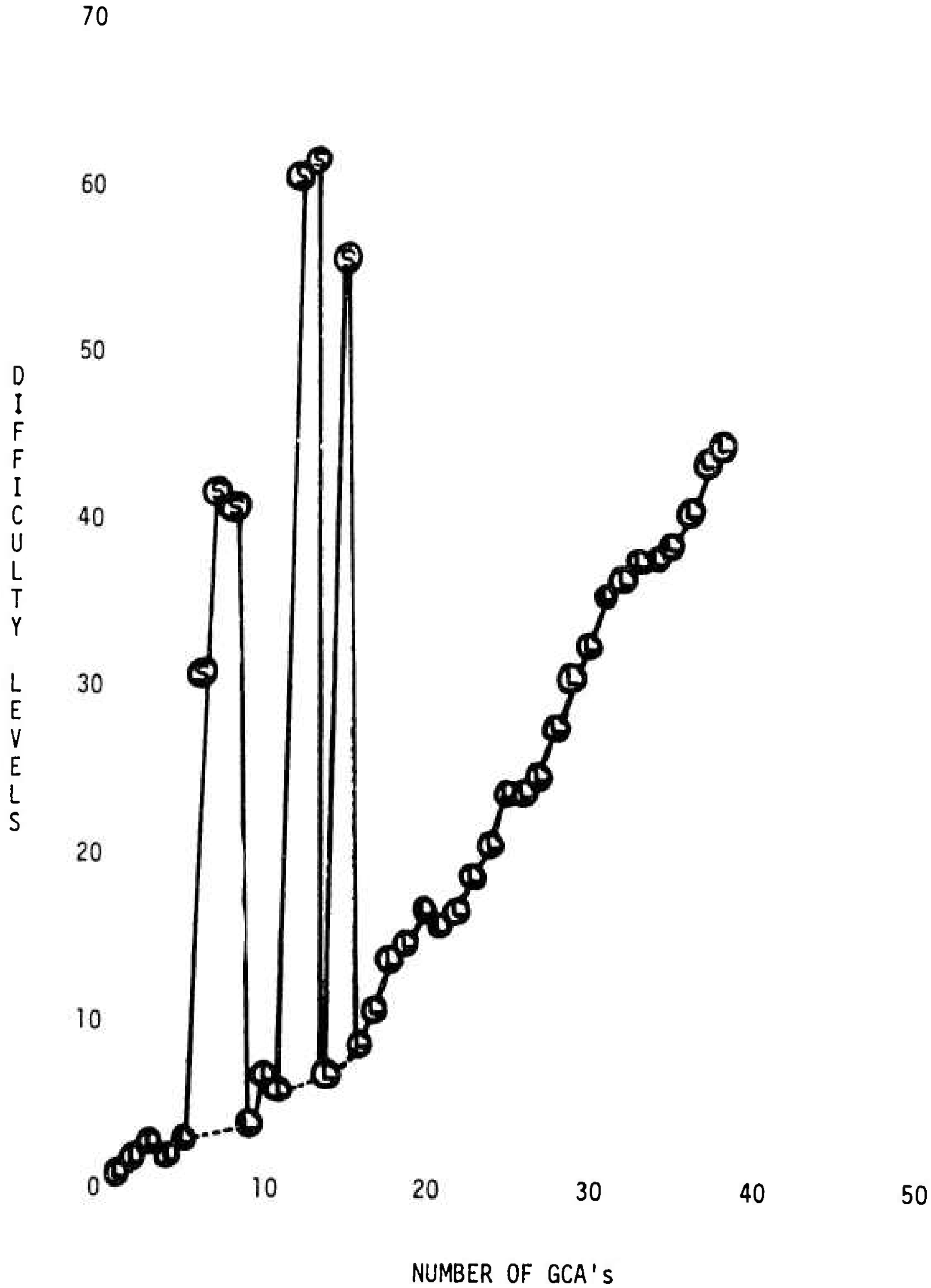

Figure B10. **Difficulty levels achieved by student 10A.**

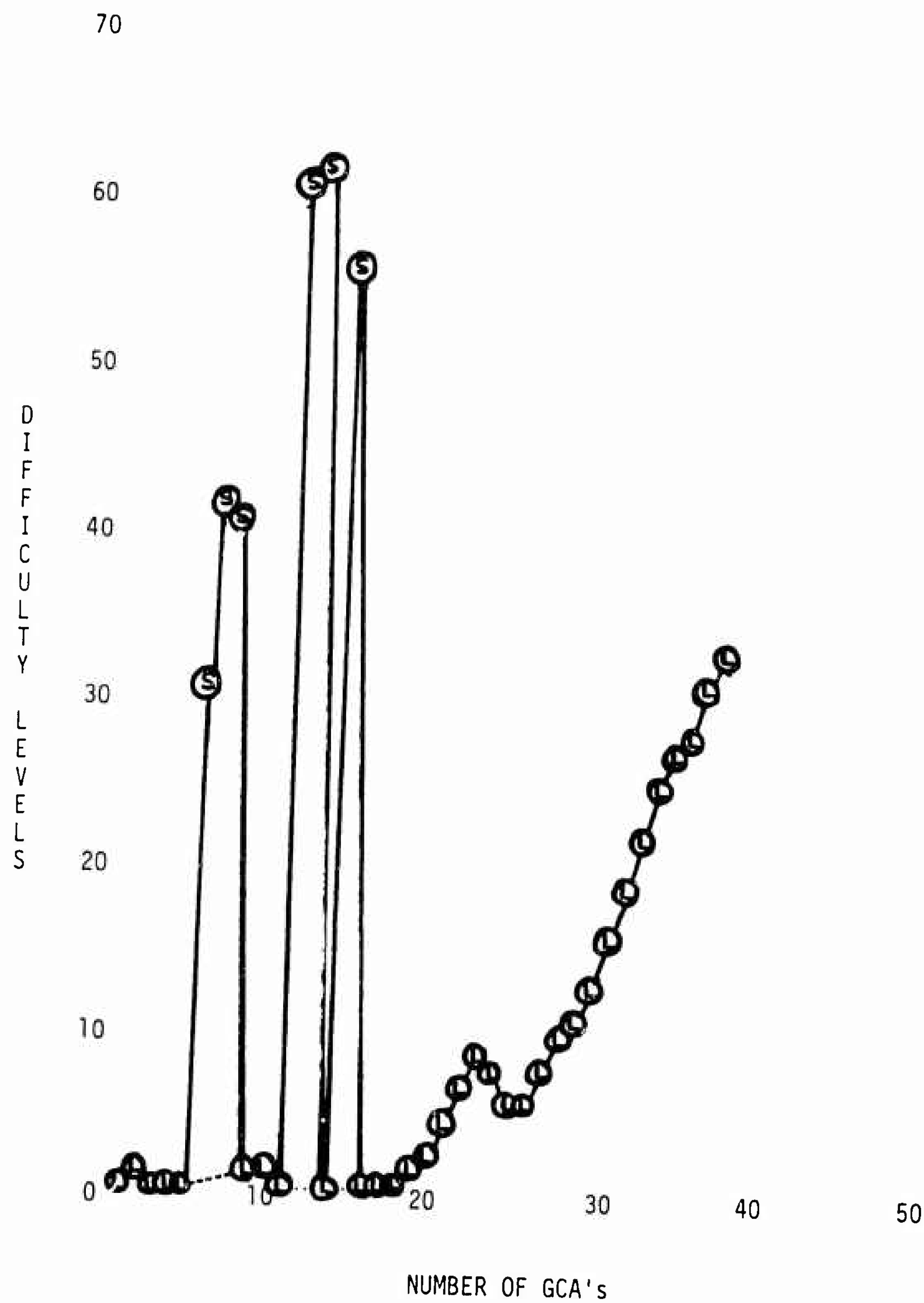

Figure B11. **Difficulty levels achieved by student 11A.**

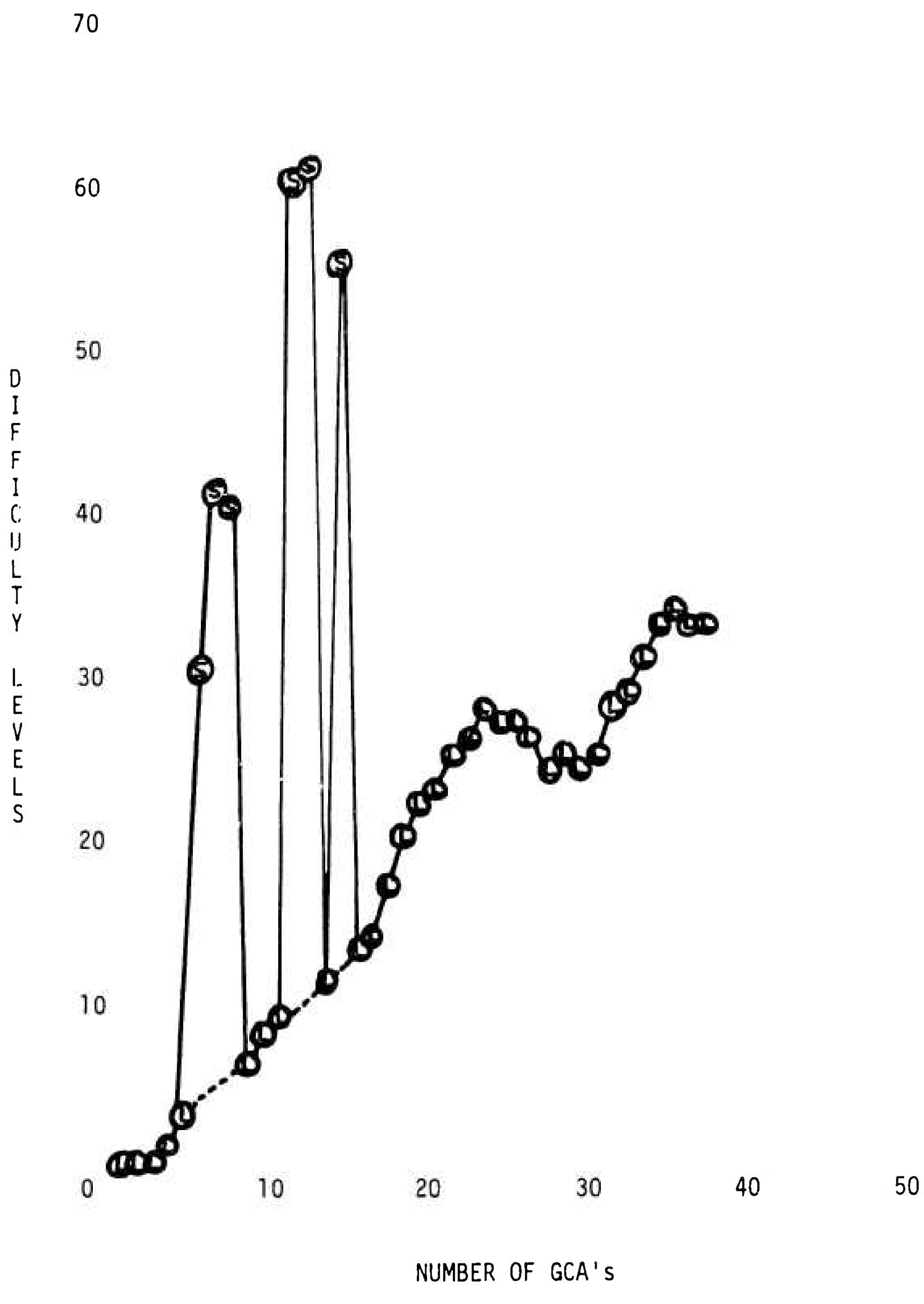

Figure B12. **Difficulty levels achieved by student 12A.**

APPENDIX C: MAINTENANCE PROBLEMS AND SYSTEM DEFICIENCIES IDENTIFIED BY OPERATOR AND MAINTENANCE PERSONNEL

Throughout the evaluation, a variety of maintenance problems and system deficiencies were identified by the operator and maintenance personnel. These problems and the subsequent action taken are identified as follows:

1. *Problem*: Voice takes too long to give message. If pilot makes a drastic correction, AFTS has to finish message before starting new message for correction.

Action Taken: None.

2. *Problem*: If pilot intercepts glide path, no scoring starts.

Action Taken: None.

3. *Problem*: Intermittent gaps appear in aircraft trace and voice pauses.

Action Taken: None.

4 *Problem*: 4010 screen wearing out.

Action Taken: Swapped main terminal with replay terminal. Have on hand part number for new tube.

5. *Problem*: Equipment cabinet needs cooling.

Action Taken: Fan installed in AFTS cabinet side. April 74.

6. *Problem*: Equipment cabinet needs hole for printer and card reader power cords.

Action Taken: Modification possible. Suggestion forwarded to contractor.

7 *Problem*: Phrase "over landing threshold" too fast.

Action Taken: None.

8.. *Problem*: Monitor buffer needs better insulation on wire.

Action Taken: Forwarded to contractor. At one time they said a redesign was in progress.

9. *Problem*: "Y" switch and interface wire needs to be heavier gage.

Action Taken: Forwarded to contractor.

10. *Problem*: All equipment in cabinet needs to be mounted better. (Flimsy).

Action Taken: None. Contractor is aware.

11. *Problem*: Replay does not print proper run number.

Action Taken: None.

12. *Problem*: Replay causes runtime error 28.

Action Taken: Corrected – June 74.

13. *Problem*: Replay prints one name on line printer.

Action Taken: System design at this point. Can be changed at any time.

14. *Problem*: Replay does not always work.

Action Taken: Corrected – June 74.

15. *Problem*: Need diagnostics to check AFTS.

Action Taken: None. TAC personnel will write our own.

16. *Problem*: Some student file run numbers are slipping through replay, or not being deleted.

Action Taken: Corrected – June

17. *Problem*: Some student level numbers are not being updated.

Action Taken: Determined as operator error. AFTS program must finish computation before it is stopped or run will not be updated. Suggestion: wait for printer to finish beofre "CONTROL A."

It was also suggested that the Logicon AFTS should have a "Malfunction Clear" Program to be initiated at touchdown, to allow the student to "Go Around" for subsequent GCA.

Logicon does not release WSTS upon completion of a GCA with Logicon inserted failures such as engine flame-out, utility hydraulics, and flaps failures.

After the emergency landing, the Logicon operator must "Cntrl A" the machine to allow the discrepancies to be cleared and then re-type into the Tektronix 4010 the pilots name, squadron, date level, etc., while the student pilot executes takeoff and climbout again.

It was suggested that the Logicon system could expedite, and more realistically control the GCA missions if it would release the malfunction program at, or just prior to, touchdown and later re-insert the emergencies required for the succeeding GCA.

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